Spinal position sense in healthy subjects and patients with ankylosing spondylitis

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SPINAL POSITION SENSE IN HEALTHY SUBJECTS AND PATIENTS WITH ANKYLOSING SPONDYLITIS

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ABSTRACT

Recovery of proprioception is regarded as an important outcome in the rehabilitation of patients with musculoskeletal injury or disease. This recognition derives from peripheral studies which report proprioceptive deficits in patients with joint pathology. These studies, together with developments in movement analysis technology, have contributed to recent interest in the clinical assessment of spinal proprioception.

This thesis describes the development of a new technique to assess spinal proprioception by position sense tests which measure repositioning accuracy in flexed and upright spinal postures. Results indicated that reliable measurements of regional spinal position sense were obtainable under naturalistic conditions using an electromagnetic movement analysis device, the 3-Space Fastrak. Spinal position sense was found to be comparable with that of peripheral joints. Range of movement was shown to have little effect on spinal position sense and this is important for the assessment of patients with restricted spinal movement.

The new technique was used to assess spinal position sense in patients with ankylosing spondylitis (AS). Pathological processes in AS target spinal entheses which are important sites of afferents subserving proprioception. There is no established aetiological basis for the changes in spinal posture which characterise this disease. The technique was therefore used to compare spinal position sense in patients and controls and to explore the association between position sense, posture and other outcome measures in patients with early disease. No differences in spinal position sense were found in patients compared to controls or in patients following longitudinal assessment over a 12-18 month period of disease progression or a two-week in-patient programme.

cont.

Elongated longitudinal assessment of spinal position sense and other outcome measures may be required to determine the aetiology of spinal deformity in ankylosing spondylitis. Assessment of spinal position sense in other groups of patients should enhance understanding of the pathological mechanisms underlying proprioceptive change.

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FOREWORD

Interest in proprioception, and especially proprioceptive rehabilitation, is growing rapidly and has been promoted by the findings of studies on proprioception in damaged peripheral joints. Little is known about normative, pathological or rehabilitative aspects of spinal proprioception. An understanding of these is essential to progress in the physiotherapy management of spinal conditions. In this work, which consists of a series of experimental studies, I contribute to this field by developing a new clinical technique for the assessment of spinal position sense. The new technique is used to obtain normative data on spinal position sense in healthy subjects and patients with ankylosing spondylitis (AS). A further contribution is made by intervention and longitudinal studies which explore the association between spinal position sense, posture and other outcome measurements in AS patients.

Chapter 1 is a review of the literature on proprioception, ankylosing spondylitis and spinal measurement. In section 1 of this review I present information on the current state of knowledge on proprioception and report on the findings of studies which suggest that proprioception is affected by abnormal articular and peri-articular pathology and may be retrained by specialised rehabilitation programmes. Section II is a review of relevant aspects of the current state of knowledge on ankylosing spondylitis (AS). Pathological processes in AS are shown to affect anatomical sites containing afferents subserving proprioception. I show that the aetiology of postural deformity in AS is unknown and that there is little substantive evidence for the long-term efficacy of physiotherapy. Recent advances in outcome measurement in patients with AS are also discussed. The final section of the review details technological advances in the measurement of spinal movement. It shows that "direct" skin fixation techniques using computerised tracking equipment provide valid measurements of spinal movement. The literature review concludes with the aims of the experimental studies which form the basis of the work.

Chapters 2, 3 and 4, detail the development and assessment of the reliability and validity of a new technique for the measurement of regional spinal position sense. The technique is shown to provide reliable measurements of spinal position sense under naturalistic conditions and to be little affected by the magnitude of movement traversed in repositioning tasks.

Chapter 5 is a cross-sectional comparative study of spinal position sense in ankylosing spondylitis patients with early disease progression and controls. No significant differences in quantitative or qualitative aspects of spinal position sense were found between the two groups. Patients demonstrated a trend towards greater position sense accuity compared to controls. The chapter concludes with a detailed discussion on these findings.

Chapters 6 and 7 investigate spinal position sense in ankylosing spondylitis patients in response to an existing in-patient rehabilitation programme and a 12-18 month time interval. Significant changes in metrology and other endpoint measures in these experimental studies were not associated with changes in spinal position sense. There were also no significant changes in spinal curvature in either study. Detailed discussions on the experimental findings and their implications are included at the end of each of these chapters.

Chapter 8 concludes the work by summarising the findings and conclusions of the experimental studies undertaken in this thesis and making recommendations for further research in the area of spinal proprioception. The technique is held to be suitable for clinical use. However, further longitudinal studies over longer time periods are recommended to determine whether associations exist between spinal deformity, position sense and other outcome measures in ankylosing spondylitis. Studies involving other groups of ankylosing spondylitis patients and other spinal patients, such as those with chronic low back pain, may help to clarify the mechanisms underlying proprioceptive change. An understanding of the relationship between spinal position sense and other functional and clinical outcome measures is necessary if the clinical relevance of any changes in proprioception is to be determined. Greater standardisation of methodological and statistical procedures is also recommended in clinical studies of proprioception.

The abbreviation "AS" is used throughout the work to refer to the spinal condition of ankylosing spondylitis. The traditional terms, "outcome" or "process" measure, which describe assessment measures, can be confusing (pp. 53-54). The more generic term, 'endpoint' or 'endpoint measure,' recommended by van der Heijde et. al. (1997), is therefore used from now on throughout the text. The abbreviation 'SEM' refers to the

standard error of measurement, a statistical calculation used to determine the 95% confidence limits about a measurement (Appendix 3).

CHAPTER 1 - LITERATURE REVIEW

PART I - PROPRIOCEPTION

1.1 INTRODUCTION

There is no single, universally accepted, definition of "proprioception." It is notoriously difficult to describe (Jerosch and Prymka 1996, Beard et. al. 1993) and there are many definitions. In general terms, however, proprioception relates to those sensations generated within the body that contribute to conscious and sub-conscious perception of the relative orientations of body parts at rest and in motion, and that are fundamental to the control of human movement. Visual input was omitted from early definitions (Sherrington 1906) and is not usually considered part of proprioception per se. Vestibular input was, however, included in Sherrington's early definition but is not always incorporated into contemporary definitions. Similarly, exteroceptive environmental cues (such as touch and pressure) and interoceptive sensations from body viscera (Vaitl 1996) are not normally included in definitions of proprioception.

Neurophysiological mechanisms subserving proprioception are complex. Early theories on proprioception centred on afferent input from muscles (Bell 1926, Sherrington 1900). Later, central efferent mechanisms, generated by the will to move, were believed to predominate (Grusser 1995). Studies on the muscles of the eye, in particular, resulted in the development of these outflow theories of proprioception (Merton 1964). More recently, clinical and laboratory experiments focused on afferent mechanisms and were designed to investigate the relative contributions of muscular, cutaneous and joint receptors. Attempts were made to remove or enhance potential sources of input and results were assessed in terms of motor behaviour, conscious sensation or electrical changes in nerves (for example, Ecklund 1972, McCloskey et. al. 1985, Burgess and Wei 1982, respectively).

The results of many laboratory experiments on animals (Ferrell 1980, Grigg et. al. 1982) were equivocal, partly due to the fallibility of achieving a pure block on unknown receptor populations and of translating the results of animal experiments to humans. Experiments on human subjects included changing muscle and tendon input by vibration (Eklund 1969,

Goodwin et. al. 1972) or selective hand postures (Gandevia and McCloskey 1976, Gandevia et al 1983), anaesthetising joint or skin receptors (Clarke et. al. 1979) and assessing the effects of joint pathology (Barrack et. al. 1983). These experiments, in particular those involving muscle and tendon vibration, led to a revitalisation of earlier concepts of the proprioceptive role of muscle receptors. More recently, clinical research on proprioception in healthy and diseased human subjects has contributed to the further understanding of proprioceptive mechanisms. Proprioception is now widely considered to be a highly complex compound sense which relies on the recruitment of multiple receptor populations (Grigg 1994). Processing of proprioceptive afferent input may also involve information from current motor commands, so called "efferent copy" (Grusser 1995), but the importance of this remains controversial (Fel'dman and Latash, 1982).

1.2 MECHANORECEPTORS SUBSERVING PROPRIOCEPTION

Proprioception is one of the functions of mechanoreceptors sited in skin, muscles, tendons, ligaments and other joint tissues. These mechanoreceptors are sometimes called "proprioceptors." Mechanoreceptors are, however, not exclusively proprioceptive and demonstrate other important functions relating, for example, to segmental autonomic modulation and nociceptive inhibition. They cannot, therefore, strictly be called "proprioceptors" and the word has been considered obsolete (Seaman 1997). Receptors subserving proprioception act as transducers which convert the mechanical energy of physical deformation into the electrical energy of a nerve action potential (Barrack et. al. 1994). Nerve impules are relayed locally via reflex loops, and transmitted to the central nervous system at varying conduction velocities and along different types of nerve fibres. They enter the spinal cord at the dorsal root ganglia and proceed via the posterior columns and cerebellum to the post-central gyrus of the cerebral cortex where they show a high degree of differentiation (Scholz and Campbell 1980, Guyton 1989, Barrack et. al. 1994).

There are many classifications which incorporate articular and other receptors supplying proprioceptive input (Wyke 1972, Newton 1982, Matthews 1988, Mapp 1995). Most classifications are based on the transmission qualities of nerves related to nerve diameter, or the location or structure of receptors. One of the problems inherent in classification generally, is that there are large populations of mechanoreceptors whose precise function is

unknown. In addition, some afferents, for example those in joint synovium, may also have an efferent function (Mapp 1995). Classification by tissue site into skin, muscle, tendon and joint afferents may be a rather misleading oversimplification of working reality. Many components of periarticular tissues are organised in series, and therefore it is rather artificial to consider receptor populations as functionally seperate (Grigg 1994). In addition, recent work suggests that there are reflex connections between joint and muscle afferents (Gillquist 1996, Lephart et. al. 1997). Finally, receptors may be classified by a variety of colourful descriptors (for example, Meissner's, Pacinian and Ruffini corpuscles, Merkel's discs) depending upon their histological appearance. The precise configuration of receptors, appears, however, to reflect the nature of the supporting tissue rather than the actual function of the receptor (Grigg 1994). Classic approaches to classification may require revision as knowledge of proprioceptive processes increases. For the purposes of this literature review, however, receptors subserving proprioception will be discussed using current classification systems.

Cutaneous and sub-cutaneous mechanoreceptors are stimulated by stretch and folding of the skin on movement. They appear to be capable of providing information important to both position and movement sense (Grigg 1994, Seaman 1997) and probably play a facilitatory, rather than direct, role in proprioception, augmenting the contribution of other afferents (Burgess and Wei 1982). This appears to be particularly important in proprioception of the hand (Grigg 1994).

In muscles, muscle spindles are highly specialised encapsulated receptors providing information which is decoded to represent static position, velocity and acceleration. This information is interpreted in terms of static joint position sense and movement sense (Mathews 1988, Hutton and Atwater 1992). Muscle spindles contain "intrafusal" muscle fibres (nuclear bag and nuclear chain) lying in parallel with "extrafusal" muscle fibres outside the spindle capsule. Sensory innervation is via group 1A and II afferents from specialised primary and secondary endings which demonstrate different sensitivities to stretch and changes in stretch (velocity of lenthening or shortening) of the extrafusal muscle fibres. Motor innervation to intrafusal fibres is via efferent dynamic and static γ-fusimotor nerves which alter the stiffness, and hence sensitivity, of the intrafusal fibres by contracting their polar regions. Fusimotor input is regulated not only by stretch and contraction of the

parent (extrafusal) muscle, which is supplied by α - motor neurones, but also by input from its antagonists and from supraspinal centres (Scholz and Campbell 1980, Ewert and Akers 1989).

In tendons, Golgi tendon organs appear to signal force-related information and, in combination with length-related input from muscle spindles, to contribute to a sense of position in space and slow changes in position (Seaman 1997). They appear to be more sensitive to forces generated by concentric muscle action than eccentric muscle action or passive stretching and are therefore most active during concentric muscle action. They also appear to be more plentiful in anti-gravity postural muscles (Nyland et. al. 1994). The role they play in proprioception appears to be highly complex and is generally poorly understood (Grigg 1994).

Joint receptors subserving proprioception have been located in capsules, ligaments and other periarticular tissues in both animals (Ferrell 1980, Grigg et. al. 1982) and humans (Yamashita et. al. 1990, McLain 1994). They have been classified by Freeman and Wyke (1967) into Type I, II, III and IV receptors. Type I, or "Ruffini" receptors, are slowly-adapting, low-threshold, receptors sensitive to position in space and slow changes in position (Barrack et. al. 1994). Located in the fibrous capsule, predominantly on the "flexion" side of joints (the side stretched by joint extension), they are excited by stretch and appear to be important in encoding stress (ie. loads) rather than strain. In most joint positions, the joint capsule on the flexion side of the joint is slack and only becomes stressed towards the limits of extension (Grigg 1994). The more globally distributed, Type II, "Paciniform," receptors are located in joint capsules and periarticular connective tissue. They are rapidly-adapting, low-threshold receptors which respond to acceleration, deceleration and hence sudden changes in joint postion (Barrack et. al. 1994). They also appear to be responsive to local compression (Grigg 1994) and may be particularly responsive at beginning and end of movement (Nyland et. al. 1994). Type III, slowly-adapting, high-threshold, receptors are located in intrinsic and extrinsic ligaments. Understanding of the role of mechanoreceptors in human ligaments is mainly through clinical studies following damage to the cruciate ligaments of the knee. These studies suggest that ligament receptors are generally most active at the extremes of physiological range where they have a primarily reflex protective function (Clark and Burgess 1975,

Burgess and Wei 1982, Barrack et. al. 1994) and where there may be a diminishing potential for muscle spindles to signal angular displacement (Grigg 1994). Finally, Type IV receptors are high threshold, non-adapting free nerve endings subserving information on pain and inflammation. They are located in ligaments, joint capsules and fat pads, and the walls of blood vessels (Wyke 1972, Nyland et. al. 1994).

1.3 CENTRAL MECHANISMS - EFFERENCE COPY AND COROLLARY DISCHARGE

Processing of afferent signals from peripheral receptors may be influenced by centrally generated signals based on current motor commands - so called "efferent copy." (Feldman and Latash 1982). This central sensorimotor integration appears to act as a shifting frame of reference for position-related afferent input. The effect of changing conditions on sensorimotor integration in healthy subjects has been the subject of motor behaviour experiments (Wrisberg and Winter 1985, Nelson 1996). These experiments occasionally report systematic biases in the reproduction of upper limb movements under conditions of a shifting starting position. This unconscious phenomenon, originally called "postural persistence," appears to reflect adaptation in the central analysis of joint position information (Selling 1930, Craske and Crawshaw 1974). Similarly, central signals related to a sense of effort may bias judgements of force. Error in the judgement of position sense may therefore occur where perceptions of the force requirements of a task differ from the actual requirements (Merton 1964, Gandevia and McCloskey 1977). Similar central influences are demonstrated in a recent study which suggests that concurrent cognitive demand may impair knee joint position sense (Wells et. al. 1994).

There is some suggestion that central neurological deficits in the calibration of position sense may exist in patients including those with scoliosis and chronic pain disorders. Studies have shown changes in upper limb position (Keesen et. al. 1992) and vibration sense (Barrack et. al. 1988) in scoliotic patients. Deficits in the reflex recruitment of the transversus abdominal muscles (Hodges et. al. 1996), in the perception of muscle tension (Flor et. al. 1992) and in reaction times (Luoto et. al. 1996) have also been observed in patients with chronic low back pain. Impaired reflex recruitment of transversus abdominus may be attributable to the influence of local proprioceptive deficits on lumbar stabilisation

rather than central proprioceptive mechanisms (Hodges et. al. 1996). Peripheral deficits in proprioception in spinal conditions are, however, less likely to be caused by local impairment of spinal proprioceptive mechanisms and may reflect central, primary or secondary, abnormalities in the processing of proprioceptive input. Historically, there have been many theories to explain the inter-relationship of afferent and efferent signals (Grusser 1995). This inter-relationship, however, remains poorly understood and continues to be a source of controversy (McCloskey 1978, Fel'dman and Latash 1982, Gandevia and Burke 1992).

1.4 CLINICAL ASSESSMENT OF PERIPHERAL PROPRIOCEPTION

Peripheral proprioception has been assessed clinically by several different types of tests which purport to assess either position sense, movement sense ("kinaesthesia") or unconscious protective reflex mechanisms mediated by proprioceptive input. Clinical tests of peripheral proprioception are usually conducted in the absence of visual input which may compensate for any proprioceptive deficit. Conversely, vestibular input is not controlled in the absence of any significant requirement to move the head.

1.4.1 Threshold testing

Tests of movement sense involve the determination of thresholds to the conscious detection of movement and its direction. Movement is applied either at a constant velocity (Skinner et. al. 1986, Barrack et. al. 1993) or as a constant stimulus (Grigg et. al. 1973, Kokmen et. al. 1977, Kokmen 1978). In constant velocity methods, slow passive movement is applied, usually at less than 0.5 degrees per minute, and proprioception is reported in terms of the angular or linear displacement at which movement is first detected. In the constant stimulus approach, discrete or oscillatory vibration type movements are used, and proprioception is quantified from the intensity of stimulus required for the appreciation of movement. The reliability of either of these approaches to the measurement of movement sense does not appear to be reported in the literature.

Movement sense tests appear to activate slowly adapting-joint afferents, such as Golgi tendon organs and Ruffini corpusles, which supply information on steady state angular

position and slow movement (Clark and Burgess 1975, Lephart et. al. 1997). Slow isotonic movement does not, however, appear to change the discharge rate of rapidly-adapting joint afferents or muscle spindle endings (Fel'dman and Latash 1982).

1.4.2 Repositioning accuracy

Position sense tests require subjects to actively or passively reproduce previous positions or ranges of movement (Barrack et. al. 1983, 1984, Skinner et. al. 1986, Barrett et. al. 1991). Position sense is usually assessed by measuring the angular error in reproducing criterion positions either directly, indirectly by "mirroring" with the contralateral limb or by using a model of the limb to indicate perceived position. Accuracy may be expressed as the "absolute" (unsigned) error or the "constant" (signed) error which takes into account overshoot or undershoot. No literature could be found which reports on the reliability of peripheral position sense tests. Position sense tests appear to involve the recruitment of rapidly- and slowly-adapting joint afferents (Barrack et. al. 1994) and muscle spindle afferents (Mathews 1988, Hutton and Atwater 1992), and may therefore be considered a more functional assessment of proprioception (Lephart et. al. 1997).

1.4.3 Postural sway

Postural sway is the term used to describe the movement of the body during quiet standing. Many different techniques have been used to determine qualitatative and quantitative aspects of postural sway from measurements made at different body sites (Jones and Barker 1996). Postural sway appears to be determined by the integration of visual and vestibular input and proprioceptive reflex activity. The relative importance of these elements continues to be the subject of research and controversy (for example, Hlavacka et. al. 1992, Simoneau et. a. 1992, Nakagawa et. al. 1993). Exaggeration of postural sway in the absence of visual input in neurological patients is the basis of the Romberg test used in clinical practice. Stimulation of afferents in the ankle, calf and erector spinae muscles by vibration has been shown to cause changes in postural sway in healthy subjects (Eklund 1969). However, a recent study suggests that proprioceptive input from the ankles and sole of the foot has little direct effect on postural sway (Aniss et. al. 1990). Despite this apparent anomaly, postural sway has, in conjunction with other techniques, been used to

assess proprioception in studies on the ankle joint (Garn and Newton 1988, Konradsen et. al. 1993).

1.4.4 Reflex control

The most recent approach to assessment of proprioception focuses on reflex aspects of proprioception (Johnson and Johnson 1993, Beard et. al. 1994a, 1994b, Konradsen et. al. 1993). This approach is based on the premise that the reflex protective response of muscles to sudden joint displacement is dependent on proprioceptive input from ligaments and other joint receptors (Beard et. al. 1993, 1994b). Beard et. al. (1994b) found that patients with anterior cruciate ligament deficiency experienced a mean hamstring contraction latency almost twice that of healthy knees. When the same experiment was repeated by other workers however, no significant differences between injured and normal knees was found (Jennings and Seedhom 1994). Similarly, a prolonged peroneal reaction time has been found in mechanically or functionally unstable ankles (Karlsson et. al. 1988, Konradsen and Ravn 1991). Later workers however, reported that there are no significant deficits in reflex peroneal latency in patients following either lateral ankle ligament injury or surgical repair of this injury (Johnson and Johnson 1993).

Proprioceptive reflexes are highly complicated and incompletely understood. Methodological details may also significantly influence results. Seedhom and Jennings (1994), for example, argued that the posterior tibial force of 100 nanometers used in earlier knee experiments was insufficient to elicit a hamstring reflex in injured knees. Lack of movement in injured knees due to joint effusion may have resulted in a delayed, transcortical stretch reflex rather than the quicker monosynaptic hamstring reflex. (Jennings and Seedhom 1994). Further investigation therefore seems necessary before the validity of reflex techniques as an assessment of proprioception can be determined.

1.5 CLINICAL ASSESSMENT OF SPINAL PROPRIOCEPTION

The association between joint disease and proprioceptive ability has led to a recent and growing interest in the measurement of spinal proprioception. Current techniques of assessment are derived from the classical tests of peripheral proprioception. Spinal

proprioception has been assessed both by determining the threshold to the detection of movement and the accuracy in reproducing spinal postures. As in peripheral testing, visual input is usually excluded. Deliberate attempts have, however, been made to control vestibular input, for example, by testing subjects in four-point kneeling (Gill and Callaghan 1998) or maintaining head position (Taylor and McCloskey 1988).

1.5.1 Threshold tests

Two studies have been conducted to assess movement sense thresholds in the spine. Taylor and McCloskey (1988), examined the ability of seated subjects to detect head on shoulder rotation, and vice versa. Movement was imposed by an electromagnetic vibrator and conducted at a range of different angular velocities. Parkhurst and Burnett (1994), used custom made equipment to impose passive movements on the lumbar spine in transverse, sagittal and coronal planes. Subjects were tested in lying and sittting. Both of these studies demonstrate the technical difficulties of imposing passive movements on the spine generally and of localising this to specific regions. Taylor and McCloskey (1988), for example, reported "considerable discomfort" in their subjects when they constrained movement using a head frame incorporating a bite bar. Similarly, Parkhurst and Burnett (1994) found their equipment to be impractical and too cumbersome for general use. In addition, the reliability of results does not appear to have been assessed in either study.

1.5.2 Repositioning accuracy

A number of studies have determined position sense, either in the trunk as a whole (Jacobs et. al. 1985, Taylor and McCloskey 1990, Ashton Miller et. al. 1992), or in the lumbar (Parkhurst and Burnett 1994, Maffey-Ward et. al. 1996, Gill and Callaghan 1998), or cervical spine (Taylor and McCloskey 1988, Field et. al. 1991, Revel et. al. 1991, 1994, Loudon et. al. 1997). Position sense is determined by the accuracy in returning to either "neutral" midline or, less commonly, non-midline positions, following active or passive displacements from these. Most studies use indirect measurement methods of measurement. Taylor and McCloskey (1990), for example, assessed trunk proprioception by the ability of subjects to relocate the position of their big toe by turning to it with their head. Jacobs et. al. (1985), used a light beam and transparent ruler to determine subjects ability to centre T1

over the pelvis following 10 cm deviations from midline in the frontal plane. Angular measurements at T1 were subtended from the sacrum. They later used the same methodology but with a two camera movement analysis system incorporating the use of infrared markers at the head, T1 and T8 (Ashton Miller et. al. 1992).

More recently, techniques involving the direct measurement of angular movements of the spine have been employed. Gill and Callaghan (1998) used the Lumbar Motion Monitor (LMM) to assess midline positioning accuracy in prone kneeling and upright standing in healthy subjects and patients with low back pain. Good intra-observer and inter-observer reliability is reported for the technique (Gill and Callaghan 1997, 1998). The LMM, however, consists of an exoskeleton attached to the spine by two harnesses and such methods of attachment have been associated with reduced accuracy of angular measurements when compared with direct skin fixation techniques (Troke et. al. 1996). In addition, a drawback of this and other studies which require the physical attachment of substantial pieces of apparatus to provide either movement and/or restraint, is that extraneous cues may in some circumstances, improve proprioception. Both of these issues appear to be addressed by a recent study of lumbar position sense which used a computerised electromagnetic tracking system, the 3-Space Fastrak (Maffey-Ward et. al.1996). Movement was recorded from small sensors attached directly to the skin overlying the spinous processes of T10 and S2 and good reliability of position sense measurements was reported. Further discussion of electromagnetic tracking systems and other methods of spinal measurement can be found in the final part of this literature review.

1.6 NORMATIVE DATA

Clinical studies indicate that proprioception may adapt in response to a variety of conditions in healthy subjects. Baseline normative data is obtainable from a wide range of studies conducted both on healthy populations and control groups in patient research. Results suggest that mean peripheral movement sense thresholds lie between 0.2 and 2.8 degrees at the elbow, 0.3 to 1.8 degrees at the shoulder and 1.2 to 5.9 degrees at the knee (Cleghorn and Darcus 1952, Barrack et. al. 1983,1984, Hall and McCloskey 1983, Skinner et. al. 1986, Blasier et. al. 1994). Movement detection thresholds for the spine have been

reported as 1.58 degrees in the lumbar region (Parkhurst and Burnett 1994) and 1.4 degrees or less in the cervical region (Taylor and McCloskey 1988).

Fewer studies have been conducted to assess position sense, but tests conducted in a wide variety of conditions suggest that repositioning accuracy lies between 2.4-5.0 degrees at the knee (Barrack et. al. 1984, Skinner et. al. 1986, Marks et. al. 1993) and 0.3-7.9 degrees in the spine (Jacobs et. al. 1985, Taylor and McCloskey 1988, 1990, Revel et. al. 1991, 1994, Ashton-Miller et. al. 1992, Parkhurst and Burnett 1994). Where models of a joint are used by subjects to indicate perceived position, reduced position sense tends to be reported. Carter et. al. (1997), for example, report mean passive knee repositioning errors of 7.1 degrees using this technique.

Direct comparison of the results of proprioceptive studies conducted on the same joint in either healthy subjects or patients is frequently complicated by variations in protocol and statistical analysis of results. Furthermore, proprioception may be influenced by a variety of experimental and natural conditions.

1.7 FACTORS INFLUENCING PROPRIOCEPTION

1.7.1 Range effects

Mechanoreceptor afferents appear to be collectively well placed to provide proprioception over the entire range of joint movement although the contribution from individual receptors may vary throughout the range. Ligamentous and capsular afferents are most active at the limits of joint movement (McCloskey 1978, Burgess and Wei 1982, Gandevia and Burke 1992, Barrack et. al. 1994, Grigg 1994), so afferent input from muscle spindles may provide the primary source of joint position sense over most of the physiological range (Burgess and Wei 1982, Grigg 1994). The complex interdependency of muscle, joint and cutaneous receptors may not only vary between individual joints but also within joints at different positions in their range. Similarly, the relationship between muscle spindle discharge and joint range/angle is highly complex (Hutton and Atwater, 1992). Afferent input varies between different muscles crossing the same joint and is related to muscle length, movement speed and spindle activation history (Gregory et. al. 1988, Gandevia and Burke, 1992), so all of these may potentially effect proprioception.

Few studies of proprioception have specifically assessed the effect of range on position or movement sense. Movement sense tests in peripheral joints tend to be conducted in a variety of mid-range positions. Barrack et. al. (1983,1984a,1984b, 1989, 1994), for example, assess knee movement sense from a position of 60 degrees (1983, 1984a,1984b), 30-40 degrees (1989), and 90 degrees (1994) of flexion and report similar results on each occasion.

Similarly, position sense tests have been carried out using a wide range of criterion reproduction angles. Studies of knee position sense, for example, have been carried out in positions between 90 degrees of flexion and full extension (Barrack et. al. 1983, Harter et. al. 1992, Co et. al. 1993, Wells et. al. 1994, Andersen et. al. 1995, Swinkels et. al. 1995, Attfield et. al. 1996, Jerosch and Prymka 1996), but only a few have explored the effects of range within the same individuals (Harter et. al. 1992, Wells et. al. 1994, Andersen et. al. 1995, Attfield et. al. 1996). The results of these latter experiments vary, with some workers finding range-related differences in position sense acuity in both healthy subjects and patients (Wells et. al. 1994, Attfield et. al. 1996) and others reporting no differences (Harter et. al. 1992, Andersen et. al. 1995). In assessments of spinal position sense the majority of studies have used the "neutral" midline posture as the criterion position but none have looked specifically at the effect of range of movement on position sense acuity. However, there is some suggestion that repositioning accuracy is better in mid-line than non-midline postures, and following smaller rather than larger displacements (Jacobs et. al. 1985, Ashton-Miller et. al. 1992, Parkhurst and Burnett 1994, Loudon et. al. 1997).

1.7.2 Circumferential joint support

There is some evidence that strapping, taping or other forms of support applied circumferentially to a joint enhance proprioception in peripheral joints. Small improvements (less than 1.5 degrees) in position sense have been reported in both patients and healthy subjects following the application of an elastic bandage to the knee (Barrett et. al. 1991, Perlau et. al. 1995) or with taping or bracing of the ankle joint (Robbins et. al. 1995, Heit et. al. 1996). Others report a significant improvement in knee position sense in bandaged healthy subjects but not in injured patients (Jerosch et. al. 1996). A recent study has also

shown a small (mean 0.59 degrees) improvement in lumbar position sense in sagittal flexion in healthy subjects wearing a lumbar brace (McNair and Heine 1999). Improvements in proprioception in response to circumferential pressure may be attributable to the effect of compression on intra-capsular pressure and resultant changes in both joint and muscle receptor discharge. This may help to explain the efficacy of strapping and other support systems which may supply little in the way of biomechanical support during athletic activities (Perlau et. al. 1995).

1.7.3 Fatigue

Recent interest in the effect of fatigue on proprioception has arisen from a culture of prevention in sports injuries and the current emphasis on the importance of muscle receptors. Several studies report a decline in position sense following a fatigue protocol (Skinner et. al. 1986, Voight et. al. 1996, Lattanzio et. al. 1997) while one found no difference (Marks and Quinney 1993). Findings generally tend to support the principle of the importance of muscle receptors in proprioception but opinion is divided on the causes of fatigue-related change. Peripheral explanations for fatigue-related changes in position sense include desensitisation of muscle spindle and joint receptors, dysfunction of extrafusal muscle fibres and histochemical factors such as local acidosis (Voight et. al. 1996, Lattanzio et. al. 1997). Proprioceptive deficits may however, be related to central rather than peripheral fatigue processes. The results of experiments which involve bilateral matching tasks in elbow joints under conditions of fatigue of the dominant arm, however, do not suggest obvious central fatigue effects (Sharpe and Miles 1993).

1.8 INFLUENCE OF PATHOLOGY ON PROPRIOCEPTION

In addition to those factors which may affect propioception in healthy people, there is a growing body of evidence which suggests that both position and movement sense are impaired by physiological aging and a variety of pathological joint conditions.

1.8.1 Aging and articular disease

Several studies have examined the effects of age or age-related pathology on proprioception. Early peripheral studies reported incidentally on minor age-related changes particularly the tendency towards greater variability of results with advancing age (Goldsheider 1889, Laidlaw and Hamilton 1937, Pailliard and Brouchon 1968). Later studies which specifically assessed age-related changes found a decline in peripheral proprioception with age (Kokmen et. al. 1978, Barrack et. al. 1983, Skinner et. al. 1984, Pai et. al. 1997, Sharma et. al.1997). This deficit has been reported in both movement and position sense and, in absolute terms, amounts to a mean decline in proprioceptive acuity of approximately two and one degree(s) respectively. There appears to be little information regarding the effect of age on spinal proprioception except for one study of young subjects which found that spinal position sense improved signficantly between the ages of 7-25 years (Ashton-Miller et. al. 1992). Proprioception may therefore, be subject to maturation effects, improving into adolescence and declining with old age.

One factor which may contribute to an age-related decline in proprioception is the presence of osteoarthritis, a common joint disease which tends to increase in incidence with age (Dieppe 1990). Several cross-sectional studies have assessed proprioception in young controls and older subjects with and without osteoarthritis and these reported an age-related decline in proprioception that was further exacerbated by degenerative joint disease (Barrack et. al. 1983, Pai et. al. 1997). Another study (Marks et. al. 1996) found no age differences in healthy subjects, but the average age of the older group was at least fifteen years younger than in other studies. However, they did find quantitative and qualitative changes in osteoarthritic knees. Patients were significantly less accurate in matching knee joint positions compared with controls and also tended to overestimate target positions. Similar changes have also been reported in the proximal interphalangeal joints of patients with rheumatoid arthritis who performed significantly worse in a finger matching task and also tended to overestimate target positions in part of the test range (Ferrell et. al. 1992).

Only one study appears to have compared healthy and arthritic joints within the same subjects and this reported significant movement sense deficits in patients compared to controls, but found no significant differences within patients between healthy and

osteoarthritic knees (Sharma et. al. 1997). The authors concluded that impaired proprioception in osteoarthritis is not exclusively attributable to the disease process and may be a contributory factor in the pathogenesis of the disease.

1.8.2 Joint replacement surgery

Early experiments to determine the proprioceptive contribution of joint afferents by local or intra-capsular anaesthesia were hampered by lack of knowledge concerning their specific proprioceptive role. This made it impossible to establish definitive criteria for selective paralysis of these receptor populations (McCloskey 1978). The subsequent development of joint replacement surgery allowed proprioception to be assessed following the surgical excision of specific joint structures such as the capsule and ligaments. Studies have been carried out to assess the effect of knee (Barrack et. al. 1983, Warren et. al. 1993, Attfield et. al. 1996, Ischii et. al. 1997), hip (Grigg et. al. 1973, Stender and Drowatzky 1994) and finger (Cross and McCloskey 1973) replacement surgery on proprioception.

Joint replacement studies generally suggest that there is no significant change in proprioception beyond the deterioration associated with osteoarthritis or aging (Barrack et. al. 1983, Ischii et. al. 1997, Stender and Drowatzky 1994). Advances in knee prosthetics however, have allowed proprioception to be assessed under a variety of joint-sparing conditions. Warren et. al. (1993) reported a within-subject improvement in passive position sense in replaced versus contralateral osteoarthritic knees regardless of whether patients had posterior cruciate-retaining or -sacrificing protheses. Furthermore, patients with posterior cruciate-retaining prostheses demonstrated superior proprioception when compared with patients with cruciate-sacrificing models. The authors attributed this improved proprioception to retensioning of ligaments following prosthetic restoration of joint surface height. This theme of soft tissue imbalance has been explored in a recent study that assessed active knee position sense in thirty-eight patients, before and after knee replacement surgery which incorporated tissue balancing procedures (Attfield et. al. 1996). Patients with knees balanced in both flexion and extension demonstrated a significant post-operative improvement in proprioception at three and six months when compared to those balanced in extension only. No differences were found between patients with posterior cruciate-sparing or -sacrificing prostheses. These results require cautious interpretation, however, since

position sense errors (mean 14.5-22.5 degrees) greatly exceeded those reported in other knee studies. The test procedure used required self-assessment of joint position on an adjacent model. The validity of this approach is questionable and appears to be associated with higher overall position sense errors (for example, Jerosch and Prymka 1996, Friden et. al. 1997).

1.8.3 Joint effusion

Studies have been carried out to assess the effect of artificially induced joint effusion on clinical tests of proprioception (Ferrell et. al. 1987, McNair et. al. 1995). Ferrell et. al. (1987) report that intra-articular injection of dextran into the healthy distal inter-phalangeal joint enhances movement sense at the joint. The authors conclude that joint effusion may affect proprioception by stretching and sensitising joint structures. Correspondingly, McNair et. al. (1995), found no differences in the performance of a knee tracking task when a moderate knee joint effusion was artificially induced. Further work needs to be carried out to assess the effect of joint effusion on proprioception. Results from experiments conducted in one region may not be generalizable to other regions. Hand proprioception, for example, may be more dependent on cutaneous input than other, larger, peripheral joints (Moberg 1983). Similarly, it may not be appropriate to extrapolate the results of studies on joints with artificially induced effusions to effusions occurring in the context of inflammation. When effusion is associated with acute inflammation, for example by inducing artificial arthritis in cat knee joints, type III and IV joint receptors have been shown to be greatly sensitized and more responsive to physiological movement (Shaible and Schmidt, 1985).

There is further neurophysiological evidence for the involvement of proprioceptive mechanisms in response to joint effusion. Both experimentally induced and pathological joint effusions may produce reflex inhibition of muscles acting over the effused joint - a phenomenon known as arthrogenous muscle inhibition (Hurley and Newham 1993). In the knee joint, for example, effusion may lead to voluntary and involuntary inhibition of the extensor muscles and thereby contribute towards the development of flexion deformity. The neurophysiology of arthrogenous muscle inhibition is poorly understood but afferents which subserve proprioception appear to be involved in the underlying neuronal pathways

(Young et. al. 1987). Arthrogenous muscle inhibition may also occur in the absence of effusion, for example, in response to mechanical stimulation of knee ligaments or other structures (Newton 1982), and traumatic or degenerative damage (Hurley and Newham 1993).

1.8.4 Ligamentous injury

Ligamentous injury is frequently viewed as part of a vicious cycle incorporating joint instability, abnormal afferent input, loss of protective proprioceptive reflexes and further joint deterioration (Barrack et. al. 1994). In general, clinical studies suggest that ligamentous damage results in loss of proprioceptive acuity which may be restored by operative repair. Complete rupture of the anterior cruciate ligament of the knee appears to raise conscious (Barrack et. al. 1989, Friden et. al. 1997) and unconscious (Beard et. al. 1993) proprioceptive thresholds. Beard et. al. (1993) found that the latency of reflex hamstring contraction in the injured knee was nearly twice that of the contralateral healthy leg. Subsequent workers, however, were unable to repeat these findings and questioned the validity of the technique (Jennings and Seedhom 1994). More conventional tests of proprioception generally report higher thresholds to the perception of slow passive movement in knees with ruptured ligaments when compared to intact knees (Barrack et. al. 1989, Friden et. al. 1997). Ligamentous strain or injury may also cause a deficit in movement sense at the ankle (Garn and Newton 1988) but does not appear to affect proprioception when assessed by reflex peroneal muscle latency (Johnson and Johnson 1993).

Ligamentous injury may also have an effect on joint position sense. Carter et. al. (1997), for example, report significant deficits in joint position sense in ligament-deficient knees when compared to healthy contralateral or age- and sex-matched knees. No corresponding differences are, however, reported following acute knee ligament injury (Friden et. al. 1997). Similarly, surgical repair of damaged anterior cruciate ligaments does not appear to be associated with position sense deficits (Harter et. al. 1992, Co et. al. 1993).

1.8.5 Non-specific injury

Several studies have investigated the effect of non-specific injuries on position sense. All of these are on the spine and are studies involving patients with lumbar (Field et.al. 1991, Gill and Callaghan 1998) or cervical (Revel et. al. 1991, Loudon et. al. 1997) pain or injury. General inclusion criteria are used and specific sites of pain or injury are unknown. Field et. al. (1991), reported less variability in lumbar repositioning in back-injured adults compared to healthy controls and concluded that position sense was superior in patients. Very few details are, however, given in their publication. Conversely, others found mean repositioning deficits of between 2.4 to 3.26 degrees in back and neck pain patients (Revel et. al. 1991, Loudon et. al. 1997, Gill and Callaghan 1998). A tendency for patients to overshoot target positions has also been noted in some studies (Revel et. al. 1991, Loudon et. al. 1997). Revel et. al. (1991) found no association between pain and position sense and concluded that differences were attributable to changes in proprioceptive input from damaged structures.

1.9 PROPRIOCEPTIVE TRAINING AND REHABILITATION

1.9.1 Proprioception in highly trained individuals

The trainability of proprioception has been assessed by comparative studies on healthy, highly trained subjects and untrained subjects, and also by studies on the effects of specialised proprioceptive rehabilitation regimes on different patient groups.

Healthy male ballet dancers were reported to have reduced postural sway compared to controls (Leanderson et. al. 1996). Comparable findings were not, however, found in female dancers and data on the differences in the amplitude of postural sway between groups was not given. A reduction in postural sway (< 0.82 mm) was also found in a group of trained subjects who had undertaken an intensive programme of proprioceptive ankle disc ("wobble board") training (Hoffman and Payne 1995). Another study suggests that knee position sense is worse in ballet dancers compared to untrained controls (Barrack et. al. 1984). The dancers in this study, however, had better knee movement sense than controls. Similarly, a significant improvement in knee movement sense has been reported in highly trained amateur gymnasts (Lephart et. al. 1996). These last two studies

demonstrated a mean difference in movement sense thresholds between trained and untrained people of 0.8 and 1.2 degrees respectively. The clinical significance of these small differences is uncertain but they do provide some experimental evidence to support the popular belief that healthy people can enhance proprioception by training.

1.9.2 Key concepts in proprioceptive rehabilitation

Traditional approaches to exercise rehabilitation or training in people without central neurological impairment focused primarily on muscle strength and range of movement. More recently, proprioception is considered as an endpoint in its own right, resulting in the development of rehabilitation programmes which specifically target proprioception. Proprioceptive rehabilitation programmes are underpinned by a number of key concepts. The first is that damage or disruption to afferents conveying proprioceptive information results in clinical deficits in proprioception. Details of the mechanisms underlying this abnormality are largely speculative. One theory, which relates to arthrogenous muscle inhibition, is that damage to joint afferents leads to a reflex reduction in α- and γ-motorneurone excitability. This, in turn, reduces muscle spindle sensitivity and voluntary muscle activation causing deficits in proprioception (Hurley 1997). Loss or reduction of reflex protective muscle contraction may then exacerbate joint instability and cause further abnormal afferent input leading to greater predisposition to re-injury and so on, in the vicious circle described earlier (Barrack et. al. 1994).

A further theory, which emanates from clinical studies of proprioception in damaged peripheral joints, is that damage to specific receptor sites causes a net deficit in proprioception. There is, however, some evidence of compensatory reserve within proprioceptive systems. Input from muscle spindle afferents, for example, may compensate for deficits in articular input following joint replacement (Barrack et. al. 1983, Ischii et. al. 1997, Stender and Drowatzky 1994). Furthermore, severity of joint destruction does not necessarily equate with the degree of proprioceptive deficit (Glencross and Thornton 1981). A further theory is that central processing of proprioceptive input occurs in the context of a central frame of reference which appears to require continual refreshment and renewal preferably with associated visual input to maintain acuity (Wann and Ibrahim 1992). On this basis, reduction in the variety or range of movement through injury or immobilization is

believed to impair proprioception. However, while immobilization may contribute to impaired proprioception in pathological joints (Norris 1995), it does not appear to be associated with clinical deficits in proprioception in healthy joints (Swinkels et. al. 1995).

1.9.3 Proprioceptive rehabilitation programmes

Proprioceptive rehabilitation programmes seek to enhance qualitative and quantitative proprioceptive input by exercises which progressively challenge proprioceptive systems. The combined effects on local proprioceptive reflexes and central motor output are believed to improve neuromuscular co-ordination and hence overall motor performance. The underlying premise is that there is sufficient redundancy in control systems to enable proprioceptive deficits to be compensated by reprogramming through specialised exercise training (Gillquist 1996). Proprioceptive rehabilitation is a relatively new concept and there is, as yet, no universally accepted standard for the components of a proprioceptive exercise regime. A variety of training programmes have, however, been devised for the ankle (Freeman et. al. 1965, Hoffman and Payne 1995), knee (Beard et. al. 1994) and spine (Norris 1995, Johannsen et. al. 1995). Closed kinetic chain exercises, in which one end of a limb is considered "fixed" (as in weight-bearing), are believed to be the optimal type of exercise for proprioceptive training of the limbs (Bunton et. al. 1993). This is in contrast to previous traditional exercise regimes which focused on open chain isometric or isokinetic muscle work such as knee extension against the resistance of weights or a machine. Closed chain exercise is considered superior in proprioceptive training in limb joints because it usually incorporates more naturalistic, weightbearing, multiplanar movements involving acceleration and deceleration (Bunton et. al. 1996, Snyder-Mackler 1996). Balance activities, for example on a rocker board or trampoline, and stretching exercises also tend to be included. Proprioceptive exercises may be progressed by a variety of means designed to intensify proprioceptive input. These include decreasing the stability of the starting position, increasing the range, speed and complexity of movement and the number of repetitions, and removal of visual feedback.

While current theory and practice tend to support concepts of adaptability within the proprioceptive system, only a few studies have directly investigated the effects of specific proprioceptive rehabilitation on proprioception or related clinical outcomes. Several studies

on peripheral joints suggest that specialised training enhances proprioception in both patients and healthy people. Patients with ligament injuries show significant improvement in proprioception when rehabilitated by proprioceptive training rather than other types of training regime (Freeman et. al. 1965, Beard et. al. 1994a). Beard et. al. (1994a) randomised patients with anterior cruciate ligament deficiency to receive muscle strengthening or proprioceptive training programmes. Using reflex hamstring latency to assess proprioception, a significantly greater improvement in mean latency was found in the proprioceptive training group. Freeman et. al. (1965) reported that treatment of ankle sprains by co-ordination exercises resulted in less functional instability at follow-up than other treatment regimes. Patients were not, however, assessed immediately post treatment but an average of nine months after injury, making it difficult to directly attribute improvement to the training programme. Furthermore, the reliability of the proprioceptive test used, based on observer rating of balance on one leg with and without visual input, was not assessed. In a more recent study, Carter et. al. (1997) found no differences in position sense in anterior cruciate-deficient knees following an intensive proprioceptive training programme. Only one study appears to have looked at training effects in healthy subjects. Hoffman and Payne (1995) examined the effect of intensive rocker board training on proprioception in twenty-eight subjects with healthy ankles. A significant improvement in postural sway was found in the training group compared with controls.

Several examples of spinal proprioceptive training programmes can be found in the literature (Desmet 1988, Norris 1995, Johannsen et. al. 1995) but no studies appear to have measured the effect of these programmes on spinal proprioception. As with peripheral joints, there is no standardised proprioceptive exercise regime for the spine and a variety of approaches are adopted (Revel 1995). Norris (1995), for example, advocates the breaking down of complex functional exercises into simple, slow and accurate movement sequences. Exercises tend to be progressed using a similar approach to peripheral joints, for example, by decreasing the stability of the surface by use of a "wobble" board or large gym ball (Desmet 1988, Norris 1995), and increasing the complexity of movements. Norris (1985) discusses proprioceptive training in the context of lumbar stabilisation and proposes a spinal stabilising system consisting of links between active, passive and neural sub-systems. Very little is known about the nature of these links, however, and they may have been over-simplified (Beard and Gill 1995).

1.10 ASSOCIATION OF PROPRIOCEPTION WITH FUNCTION AND OTHER ENDPOINTS

While many studies report statistically significant changes in proprioception in response to pathology, surgery, training and other interventions, the impact of these changes on functional and other outcomes is rarely investigated. The clinical implications of a typical mean peripheral repositioning deficit of 2-5 degrees, are therefore difficult to establish particularly when differences of this magnitude may exist between healthy individuals. At the extreme end of the spectrum, patients with gross sensory deafferentation due to trauma or disease may experience considerable functional difficulties (Rothwell et. al. 1982, Cole and Sedgewick 1992). These patients generally require extreme concentration and continuous visual feedback to perform even simple functional tasks. They may also have difficulty in sustaining muscle contractions, in matching muscle force to task requirements, and little or no ability to match limb positions. Everyday functions such as walking or dressing are either impossible or extremely difficult. With intensive training, some function may be restored. Cole and Sedgewick (1992) report on the exceptional case of a man who, despite complete loss of large myelinated sensory afferents below the neck, was able to relearn activities of daily living such as walking and eating. Even in extreme cases, therefore it may be possible to partially compensate for proprioceptive loss by increasing reliance on visual and other cues. Localised joint deafferentation, for example, that found in neuropathic (Charcot's) joints in diseases such as tabes dorsalis or diabetes mellitus, is classically associated with joint instability and gross arthritic changes (Currey 1986) suggesting a vital role for proprioception in joint protection (Barrett et. al. 1991).

Clinical studies of proprioception following single joint impairment rarely investigate other outcome measures. Recent developments in proprioceptive rehabilitation, particularly following knee injury have, however, resulted in a growing interest in the association between proprioception and other endpoints. In a study of proprioception following anterior cruciate repair, Barrett (1991) found a strong association between patient satisfaction, function and knee joint position sense. There was, however, no association between scores derived from clinical testing of ligamentous laxity and measurements of knee joint position sense. Results are difficult to interpret since the validity and reliability of the customised endpoint measures (with the exception of the knee function score) do not

appear to have been established. Beard et. al. (1993) report a correlation between a similar validated knee function score (Lysholm and Gillquist 1982) and an increase in reflex hamstring contraction latency in patients with ruptured anterior cruciate liagaments. In a later study (Beard et. al. 1994a), a corresponding correlation between improvement in reflex hamstring contraction latency and function was reported following muscle strengthening or proprioceptive rehabilitation programmes. However, the association between proprioception and knee function/knee stability remains unclear, and significant improvements in these measures may occur in the absence of proprioceptive change (Carter et. al 1997).

No studies appear to have assessed the effect of proprioceptive rehabilitation on spinal proprioception and related endpoints. Johannsen et. al. (1995), however, looked at clinical outcomes following random allocation of forty chronic low back pain patients to endurance or co-ordination training regimes. Although both groups demonstrated significant improvements in pain, mobility and disability scores, no differences were found between groups on completion of the programme and at three months follow-up. The results of this trial should, however, be interpreted with caution due to high drop out rates and the use of unvalidated mobility and disability scores.

1.11 SUMMARY - PART I, PROPRIOCEPTION

Proprioception is a composite sense involving input from cutaneous, joint and muscle receptors. It incorporates a sense of both position and movement. Classic tests of position sense assess repositioning accuracy and, unlike movement sense tests, involve the recruitment of both joint and muscle receptors in a manner representative of normal function. The inter-dependency of afferent populations is an emerging theme in proprioception and one which suggests that factors which affect specific afferent groups may influence proprioception as a whole. Clinical tests suggest that proprioception can adapt in a variety of experimental and pathological conditions. The reliability of these tests in patients and healthy controls is, however, frequently unreported. Deficits in proprioception have been reported in pathological conditions affecting the spine and peripheral joints. The mechanisms underlying these deficits are poorly understood but are commonly attributed to local damage to receptors conveying proprioceptive input. There may, however, be a primary central deficit in the calibration of position related input in some pathological conditions. There is some evidence that position sense may be restored by specialised rehabilitation programmes. The essential requisites of these programmes have yet to be established and are dependant on a more precise understanding of the mechanisms involved. The functional implications of small deficits in proprioception remain relatively unexplored and very few studies assess position sense in combination with other related endpoints.

LITERATURE REVIEW - SECTION II

PART II - ANKYLOSING SPONDYLITIS

1.12 INTRODUCTION

1.12.1 Definition

Ankylosing Spondylitis (AS) is an inflammatory rheumatological disease affecting axial and peripheral joints. It is a seronegative spondyloarthropathy highly associated with the histocompatibility antigen HLA B27. The primary pathology is one of inflammation, erosion, fibrosis and, ultimately, ossification of entheses which are the sites of attachment of joint capsules, ligaments and tendons into bone. These changes characteristically originate in the sacro-iliac joints and ascend the spine. Two forms of the disease have been identified - primary (idiopathic) which occurs in the absence of other rheumatological disorders and secondary, which is associated with psoriatic arthropathy, inflammatory bowel disease and Reiter's syndrome (Russell 1998). The precise etiology of AS is unknown but is believed to involve the interaction of genetic factors (HLA-B27) and enviromental triggers (Calin 1998).

1.12.2 Diagnosis

Much debate surrounds the criteria for diagnosis of AS and the search for definitive workable criteria in both early, pre-radiological, and later stages of the disease continues. Criteria were originally formulated in Rome in 1961 (Kellegren et. al. 1963) and subsequently revised in New York in 1966 (Bennett and Wood 1968). The New York criteria featured a number of changes including the incorporation of radiographic evidence of sacroiliitis. They were, however, criticised on a number of grounds relating, for example, to sensitivity, specificity, and inclusion and exclusion criteria (Moll 1986, Gran and Husby 1993). Deficiencies in the New York criteria led to the development of new, simpler, symptomatic criteria obtainable by questionnaire (Calin 1977). These criteria advocated diagnosis by three or more of the following; onset before age 40 years; insidious onset; minimum duration of three months at first attendance; an association with morning stiffness; and improvement by exercise. They were, however, considered by some to be insufficiently discriminatory (Gran and Husby 1993, Van der Linden 1984). Van der Linden

et. al. (1984) attempted to improve matters by modifying the original New York criteria. These modified New York criteria for AS (Table 1) incorporate symptomatic and radiological evidence of AS and are in common use in both clinical and research settings. They include radiological evidence of bilateral sacroiliitis which has been reported to have acceptable observer error (Calin 1996, Dougados et. al. 1991).

Clinical criteria

1. Low back pain and stiffness for more than 3 months which improves with exercise but is not relieved by rest

2. Limitation of motion of the lumbar spine in both the sagittal and frontal planes

3. Limitation of chest expansion relative to normal values corrected for age and sex

Radiological criterion

Sacroiliitis ≥2 bilaterally or grade 3-4 unilaterally*

Grading of criteria

1. Definite AS if the radiological criterion is associated with at least 1 clinical criterion

2. Probable AS if
   (a) Three clinical criteria are present
   (b) The radiological criterion is present without any signs or symptoms satisfying the clinical criteria (other causes of sacroiliitis should be considered)

*See Table 46, p. 256

TABLE 1 - Modified New York diagnostic criteria for AS (van der Linden et. al. 1984)

The limitations of existing clinical diagnostic criteria are widely recognised. Clinical features may pre-empt radiological changes by up to 4 years in men and 6 years in women (Gran and Husby 1993) and there are currently no established criteria for pre-radiological diagnosis. Extraspinal involvement is common in AS (Dougados et. al. 1998) and there may also be a large population with largely asymptomatic, unrecognised disease (Calin and Fries 1975). Changes in the epidemiology of AS may reflect a general broadening of the spectrum of the disease and its clinical variants (Calin et. al. 1988, Russell 1998) and early

classifications are generally believed to be too restrictive (Calin 1998). In response to this, the European Spondyloarthropathy Study Group has devised preliminary criteria for the classification of spondyloarthropathies. These encompass a broader spectum of disease and enable a diagnosis of spondyloarthropathy in the absence of radiological change (Dougados et. al. 1991). Similarly, Amor (1991) has developed a diagnostic point scale which demonstrates good sensitivity and specificity and is not dependent on radiological criteria. These most recent classifications reflect the growing trend towards the use of criteria based on clinical examination, history and self-reported questionnaires rather than more expensive, invasive laboratory and radiological tests.

1.12.3 Prevalence, pattern and prognosis

Estimates of the prevalance of AS are highly dependent on characteristics of the population under study such as age, gender, race and source. Hospital studies, for example, consistently report a prevalence of around 0.10 - 0.20 % while blood donor studies report higher levels of up to 2%. The influence of race can also be quite marked as shown by a recent study that reported a prevalence of between 1.1-1.4 % in Norweigen Lapps and 4-6% in male Haida, native inhabitants of northern Canada (Gran and Husby 1998). Ninety percent of people diagnosed with primary (Gran and Husby 1998) and 50% of those with secondary AS have the HLA B27 histocompatibility antigen (Calin 1998).

The reported male to female ratio of AS varies greatly ranging from around 10:1 (Gran and Husby 1998) down to 1:1 (Calin and Fries 1975) and also varies with age (Calin 1998). It is now widely held that, due to a variety of diagnostic and social factors, the prevalence of AS in women has been underestimated (Marks et. al. 1983). Several studies have indicated variations in the pattern of disease between men and women. Women, for example, may be more likely to have peripheral joint involvement, to be diagnosed later (Marks et. al. 1983, Wordsworth and Mowat 1986) to have a positive family history (Will et. al. 1990) and a better long term outcome (Guillemin et. al. 1990). They may be more likely to have "skip" lesions - pelvic and cervical spine lesions in the absence of lumbar involvement (Calin and Elswood 1988). Clinical and radiographic features may also develop more slowly in women (Khan 1988). Nevertheless, such pronounced clinical differences between males and females are not always apparent (Gran et. al. 1985).

The presentation of AS, as well as its prevalence, may be influenced by the study population. AS classically presents in late adolescence and early adulthood (Khan 1998) but there is a trend towards a later age of onset, particularly in developed countries. This may reflect later exposure to, or changing pathogenicity of, infective triggers (Will et. al. 1990). Later age of onset has also been associated with HLA B27 negative individuals (Khan 1998). Several prospective and retrospective studies have been carried out to determine the natural history of the disease and these show that the pattern of disease is highly variable but that some generalisations can be made regarding its presentation.

AS is generally characterised by "flare-ups" of several days duration. The first 10 years are particularly important in relation to disease development with most pain and loss of function occurring during this period (Gran and Skomsvoll 1997, Carette et. al. 1983). Axial x-ray changes become significantly worse and tend to ascend the spine with time (Calin and Elswood 1988). A minority of cases may progress to complete vertebral fusion, known as "bamboo spine" due to the radiographic appearance.

Peripheral joint involvement occurs in 20-40% of patients (Calin 1998) and is most common in the large synovial joints of the hips and shoulders. Hip involvement may occur in 17-38% of cases (Khan 1988) and is associated with an early age of onset and a poor prognosis (Calin and Elswood 1988, Amor et. al. 1994). Other predictors of poor outcome include early severity, peripheral joint involvement, extra-articular features (including iritis), stage at diagnosis and therapeutic intervention (Carette et. al. 1983, Guillemin et. al. 1990, Amor et. al. 1994, Khan 1998). Certain psychosocial and economic factors such as low treatment compliance, heavy manual work and cold working conditions have also been associated with a poor prognosis (Guillemin et. al. 1990, Khan 1998).

AS does not appear to "burn out" in terms of an indefinate period of remission though up to 1% of patients may remain in remission for two years or more (Kennedy et. al. 1993). Although progressive, it appears to be relatively benign in terms of severe functional impairment (Mau et. al. 1988) with most patients retaining the capacity to work even after long term disease (Wordsworth and Mowat 1986). AS rarely shortens the life span though occassionally premature death does occur due to complications such as cervical subluxation

or aortic insufficiency (Carette et. al. 1983). There is some suggestion of both real and interpretive change in the epidemiology of AS including later age of onset, earlier diagnosis, increasing diagnosis in women and less aggressive forms of disease (Calin et. al. 1988, Khan 1988, Gran and Husby 1993). However, there is also some evidence of an increasing incidence of severe, aggressive disease unresponsive to conventional treatments (Haslock 1998). These reports may reflect current epidemiological and clinical practice as well as changes in aetiological factors (Will et. al. 1990).

1.13 PATHOLOGY OF AS

1.13.1 Entheseal and articular pathology

Much of the pathology of AS is attributable to changes at the enthesis - the site of insertion of tendon, ligament or articular capsule into bone. The enthesis is a richly innervated site of high metabolic activity divided into four zones. The first zone, the actual tendon, ligament or joint capsule, merges into a second zone of unmineralized fibrocartilage. This becomes mineralized (third zone) and merges into the fourth zone - the bone itself. Fibrous connections between the four zones, "Sharpey's" perforating fibres, make for an extremely strong attachment to bone (Ruhoy et. al. 1998). Alteration at entheses is termed enthesopathy. The enthesopathy of AS appears to have been recognised only fairly recently, with the earliest, most comprehensive description probably being that of Ball (1971). Early studies of pathology in AS focus on macroscopic bony changes and reflect the radiological and autopsy techniques available at the time (Romanus and Yden 1952, Ball 1971). Later developments, such as computerised tomography, magnetic resonance imaging (Tyrrell et. al. 1995, Shaibani et. al. 1993), ultrasound (Lehtinen et. al. 1995) and scintography (Aburano et. al. 1990) have further advanced understanding of the underlying pathological mechanisms.

In AS, enthesopathy is characterised by inflammation, erosion (associated with eburnation of adjacent bone) and healing by fibrosis and ossification. Where it exists, it appears to be a constant phenonomen and unresponsive to commonly used drugs such as sulphasalazine (Lehtinen et. al. 1995). It may affect articular and extra-articular entheses in both the axial and appendicular skeleton. Changes within synovial joints have been compared to those found in rheumatoid arthritis. These include enthesopathy (Ruhoy et. al. 1998), synovitis

and, occasionally, hyperplasia of synovial tissue to form pannus across the articular surface (Vernon-Roberts 1998).

The earliest and most characteristic radiographic findings are seen in and around the sacroiliac joints. Inflammatory processes in subchondral bone cause erosion and sclerosis, particularly on the iliac side of the joint. Reactive bone formation may result in ossification of the joint capsule (Vernon-Roberts 1998). This, combined with ossification of the many adjacent ligaments, may result in ankylosis of the joint (Khan 1998). A comparable process also occurs in spinal synovial apophyseal joints. Enthesopathy at sites of capsular attachment to ligaments and bone causes progressive ossification of the joint capsule. This, in combination with bony changes in the articular cartilage itself, may lead to bony ankylosis of the apophyseal joint. Similar changes may also occur at costovertebral and manubriosternal joints and at the symphis pubis (Vernon-Roberts 1998).

In intervertebral joints, the site of attachment of the outer fibres of the annulus fibrosis to the anterior, lateral (and occasionally posterior) margins of the vertebral body is a common site of enthesopathy (Cawley et. al. 1972, Ruhoy et. al. 1998). Reactive bone formation may lead to ossification of the outer margins of the annulus fibrosis of the intervertebral disc. The resulting vertical spurs of bone or "syndesmophytes" are a classical radiographic feature of primary AS. Syndesmophytes appear to extend by cycles of inactivity or stability followed by renewed inflammation and new bone formation (Ball 1971). They may ultimately join, bridging and immobilizing the intervening joint while retaining the integrity of the intervertebral disc. If the disease progresses, however, bridging by ossification may occur within the joint resulting in destruction of the disc itself (Vernon-Roberts 1998).

In addition to syndesmophytes, enthesopathy may result in other radiographic lesions such as a loss of definition of vertebral bodies giving a squared appearance on X-ray (Aufdermaur 1989, Cawley et. al.1972). Although initially attributed to involvement of the anterior longitudinal ligament, squaring of vertebrae may reflect a primary inflammatory disintegrative process within the vertebral cortical bone itself (Aufdermaur 1989). The anterior longitudinal ligament may not typically be involved in enthesopathy (Vernon-Roberts 1998, Aufdermaur 1989) but ossification has been observed in a number of cases (Simmons et. al.. 1991). Extra-articular spinal enthesopathy has also been reported in the

ligamenta flava (Avrahami et. al.1988, Viitanen and Suni 1995), interspinous and ilio-lumbar ligaments (Calin 1993). Ligamentous lesions may not only be confined to the enthesis. Focal inflammation resulting in fibrosis and ossification has also been reported at other, non-entheseal, ligamentous sites (Ball 1971, Vernon-Roberts 1998).

AS may also affect extra-spinal synovial joints such as the hip, knee and glenohumeral joints. As in the axial skeleton, enthesopathy and other inflammatory processes may result in extensive ossification of the joint capsule and intra- and extra-articular ligaments. Enthesopathy may also occur at non-articular sites such as the ilia, greater trochanters, ischial tuberosites, pubic rami and calcaneum (Vernon-Roberts 1998).

While enthesopathy is now recognised as the primary pathology of AS it is also seen in other conditions and is a characteristic of the other seronegative spondyloarthropathies such as Reiter's syndrome, psoriatic arthritis and enteropathic arthropathies (Haslock 1998). It has also been reported in osteo-and rheumatoid arthritis and non-rheumatic conditions such as physical trauma, obesity and diabetes mellitus (Ruhoy et. al. 1998). Abnormal posture may, in itself, cause enthesopathy due to changes in mechanical forces at entheseal sites (Van der Linden 1990). Enthesopathy and other pathological changes associated with AS, such as destructive end plate lesions and fibrous or bony ankylosis of sacro-iliac joints, may also be part of the normal aging process (Shaibani et. al. 1993, Vernon-Roberts 1998).

1.13.2 Muscle pathology

Several studies report muscle changes in both early and more advanced AS (Hopkins et. al. 1983, Carraba et. al. 1984, Cooper et. al. 1991, Faus-Riera et. al.1991, Simmons et. al. 1991, Waragai and Shinotoh 1994). Enzymatic and electromyographic studies have been conducted in addition to biopsy of paraspinal and limb muscles. Attempts have been made to correlate findings with clinical measures of muscle strength and disease activity and, in some studies, to make comparisons with healthy controls (Faus-Riera et. al. 1991, Carraba et. al. 1984) or patients with mechanical back pain (Cooper et. al. 1991). The results of these studies are equivocal and occasionally contradictory.

Reported histological changes include atrophy of type II (and occasionally type I) muscle fibres, the presence of angular and core or targetoid fibres in paraspinal and quadriceps muscle, fatty infiltration and fibrosis. Histological muscle changes have also been reported in non-axial muscles such as the deltoid, quadriceps (Hopkins et. al. 1983, Faus-Riviera et. al. 1991) and biceps (Waragai and Shinotoh 1994) leading to speculation that muscle involvement may be generalised rather than localised in AS. While muscle changes are widely reported, speculation continues as to whether they are primary or secondary, and neuropathic or myopathic in nature. Neuropathic explanations include denervation (Simmons et. al.1991), for example, as a result of damage to the posterior branches of the spinal nerves (Carrraba et. al. 1984) or reflex arthrogenous inhibition due to changes in spinal apophyseal joints (Cooper et. al. 1991). Myopathic hypotheses include primary paraspinal muscle fibrosis (Cooper et. al. 1991) and inflammation (Waragai and Shinotoh 1994) or secondary changes related to enthesopathy (Carraba et. al. 1984, Cooper et. al. 1991), pain, and reduced (Faus-Rieva 1991) or increased activity or drug therapy (Hopkins et. al. 1983). A further, recent explanation involves inflammatory catabolism promoted by an increase in inflammatory mediators (Calin et. al. 1993)

Histological muscle changes, for example selective atrophy of type II muscle fibres, have also been reported in other rheumatic conditions such as osteoarthritis and rheumatoid arthritis (Ytterberg et. al. 1994) and may even be partially attributable to a normal physiological response to aging (Simpson 1993). Histological muscle changes may be independent of disease severity (Cooper et. al. 1991) or, conversely, be associated with disease-related variables such as muscle weakness (Hopkins et. al. 1983), enthesopathic activity, or changes in electromyography or serum enzyme levels (Faus-Rieva et. al. 1991).

Although sample sizes are small in AS studies, presumably due to the invasive nature of some procedures, muscle changes do appear to be a feature of both early and advanced AS. Whether these changes represent a primary inflammation of muscle, a secondary response to disuse or therapy (Hopkins et. al. 1983), or are caused by other neurogenic or metabolic mechanisms has yet to be determined.

1.13.3 Bone pathology

The debate on primary versus secondary aspects of disease in AS is reflected in recent findings on bone. A reduction in bone mineral density is generally believed to be secondary to fusion and immobilisation of the spine (Moll 1986). Recent findings, however, suggest that primary changes in the density and structure of trabecular and cancellous bone occur in the axial and peripheral skeleton even in early stages of the disease (Lee et. al. 1997) and, as in muscle, may be a response to inflammatory catabolism (Calin 1993). Further work needs to be carried out to determine whether changes in bone are useful markers of disease.

1.14 CLINICAL FEATURES

The key clinical features of AS are pain, stiffness, loss of movement and changes in spinal posture. These may combine to cause a loss of function. Fatigue is also emerging as an important feature (Garrett et. al. 1994). The commonest extra-articular manifestation is acute anterior uveitis (Khan 1998).

1.14.1 Pain

AS typically presents with an inflammatory low back pain before the age of 40 years. Pain, which tends to be bilateral, is commonly felt over the gluteal and sacroiliac regions and occasionally the lumbar spine. Characteristic features include an association with morning stiffness and improvement with exercise (Khan 1988). Low back pain which is worse at night and unrelieved by lying down has also be shown to demostrate high sensitivity for AS (Gran 1985). Peripheral and axial pain is primarily attributable to enthesitis and also synovitis of involved joints (Dougados et. al. 1998) and may be associated with localised tenderness at axial and non-axial entheseal sites (Khan 1988). Non steroidal anti-inflammatory drugs (NSAIDs) have a "dramatically significant beneficial effect" on pain, particularly on axial pain (Dougados et. al. 1998) but do not have any disease modifying effect (Haslock 1998).

1.14.2 Stiffness and loss of movement

Duration of morning back stiffness is indicative of the degree of inflammation present. Initial loss of movement may be attributable to pain and muscle spasm (Moll 1986, Laurent et. al. 1991, Khan 1998). This loss may later be compounded by calcification of ligamentous, tendinous and capsular entheses. Deficits may occur at any involved joint in any plane of movement. Early loss tends to occur in the lumbar spine, particularly on lateral flexion. This movement has been shown to have good discriminative power in distinguishing between AS and other spinal conditions (Gran 1985). Antalgic postures, such as flexion of the hip joint, may cause adaptive tissue shortening and muscle atrophy, thus resulting in further loss of movement.

1.14.3 Postural changes

Postural change is a hallmark of ankylosing spondylitis. The severe postural "question-mark" deformity described in authoritative texts (Moll 1986) was long considered ubiquitous and almost synonomous with the disease. Deformity of this type now presents less commonly and only a minority of individuals appear to go on to develop aggressive disease associated with gross postural change. This changing presentation may represent a widening of the diagnostic spectrum, earlier diagnosis, advances in treatment and even changes in the epidemiology of the disease itself (Calin et. al. 1988). Despite the less severe presentation, postural changes are manifest in AS, begin much earlier than previously thought (Moll 1986, Becker-Cappeller 1994), show large individual variation and tend to become more marked with time (Viitanen et. al. 1995). Characteristic spinal changes include flattening of the lumbar lordosis, development of a thoracic kyphosis and cervical protraction manifesting as an increase in flexion and extension of the lower and upper cervical spine respectively.

Consideration of postural changes in classic medical or specialist physiotherapy texts is usually limited to brief descriptions with little or no discussion of causation (for example, Brewerton 1986, Moll 1980, Hyde 1980).

Descriptions may even be presented as inherently aetiological:

> 'The patient loses normal posture because of flattening of the lumbar spine and development of a gentle thoracic kyphosis.' (Khan 1998, section 6, p.16.4)

Where explanations do exist, postural adaptations have classically been considered as primarily antalgic in origin (Barefoot 1981, Moll 1986, Clarke et. al. 1987, Gall 1994, Dougados et. al. 1998) and compounded by the pull of gravity (Barefoot 1981, Gall 1984, Simmons et. al. 1991). Early hip involvement is also sometimes cited as a cause of hip flexion contractures leading to loss of the normal lumbar lordosis (Khan 1998). Flexion of the lower cervical spine and extension of the upper cervical spine are usually described as secondary compensatory mechanisms to maintain the visual field (Becker-Capeller 1994). The association between hip flexion contracture and flattening of the lumber lordosis is not immediately obvious. Hip flexion contractures in other conditions, such as osteoarthritis of the hip, tend to be associated with an increased lumber lordosis (Corrigan and Maitland 1983). The psoas and iliacus muscles, both strong hip flexors, can increase the lumbar lordosis by acting via their upper attachments to the vertebral bodies and the iliac fossa respectively. Consequently, a common clinical test to expose fixed flexion contracture of the hip involves obliteration of the compensatory lumbar lordosis by maximum flexion of the opposite hip (Asim 1998).

Only four detailed explanations of the postural changes associated with AS could be found in the literature (Downey et. al. 1987, Simmons et. al. 1991, Becker-Capeller 1994, Viitanen and Suni 1995). Viitanen and Suni (1995) attribute reduced lumbar lordosis to antalgic lumbar flexion in response to apophyseal joint inflammation. Thoracic kyphosis is explained by reduced mobility in the thoracic spine causing abnormal anterior loading of vertebral bodies. Changes in elasticity of the anterior longitudinal ligament and inflammation of spinal fascia are also mentioned as posssible aetiological factors. Simmons et. al. (1991) studied nine patients with severe deformity referred for spinal surgery. Seven of these patients had either reduction, or reversal, of the lumbar lordosis. Biopsy of paraspinal muscles suggested severe muscle disease. Lack of inflammatory changes in muscle lead the authors to conclude that deformity is the result of muscle weakness due to a primary denervating process. Becker-Cappeller (1994) devotes four pages to an explanation

of posture in a Swiss AS newsletter which is based on the assumption that the first signs of AS begin in the sacro-iliac joints. Posterior tilting of the pelvis, he believes, is an automatic antalgic response to inflammation of the sacro-iliac joints which results in a decreased lumbar lordosis and a compensatory thoracic kyphosis. The centre of gravity shifts to a position in front of the body. This, coupled with weakness and shortening of cervical and abdominal muscles, further exacerbates the thoracic kyphosis. There is a compensatory increase in the cervical lordosis to maintain the field of vision.

These theories on the aetiology of spinal postural deformity in AS are speculative and based either on clinical experience or laboratory findings such as muscle biopsy studies. None have been experimentallly investigated. A further potential cause of spinal deformity in AS patients, however, might be a diminished awareness of spinal posture due to the high specificity of disease processes for spinal entheses and other soft tissues which are important sites of receptors which convey position sense (see p. 47). Most importantly in AS, these include ligamentous, tendinous and annular entheses, facet joint capsules, ligaments and paraspinal muscles (Amonoo-Kuofi 1982, Nitz and Peck 1986, Ford et. al. 1988, Yamashita et. al. 1990, 1993, McLain 1994). As discussed in the previous section (pp. 31-35), position sense appears capable of both transient and long-term adaptation in response to a variety of physiological and pathological conditions associated with damage to structures containing proprioceptive afferents. These conditions include aging, elective and accidental trauma and diseases such as rheumatoid arthritis. Enthesopathy in particular appears to be a causal factor in proprioceptive change. It is, for example, a feature of physiological aging which has been shown to be associated with peripheral deficits in proprioception (Barrack et. al. 1983, Marks 1996, Pai et. al. 1997). Similarly, high densities of receptors with a proprioceptive function, have been found in cruciate ligament entheses and damage to these ligaments causes proprioceptive impairment (Barrack et. al. 1989, Friden et. al. 1997). Changes in spinal position sense, as a result of proprioceptive deficits secondary to enthesopathy, may therefore be a factor underlying postural deformity in AS.

1.15 ASSESSMENT OF AS

1.15.1 Introduction

The last decade has seen an escalation of interest in the assessment of AS with the resultant development of new approaches to clinical metrology. The accepted rheumatological paradigm for assessment has been a subdivision into 'process' and 'outcome' measures. Process measures, usually defined as those ordered or conducted by medical staff, include assessments such as biochemical analysis, imaging techniques, and lung function tests. Correspondingly, outcome measures are those which 'examine the clinical consequences of disease' (Bellamy 1998) and are usually 'defined more in terms of the patients point of view' (Calin 1995). They frequently incorporate self-reported patient assessment of variables such as discomfort and psychological well-being. Outcome measures may be based on the five classic dimensions of outcome; death, disability, discomfort, iatrogenic reactions and economic cost (Fries and Bird 1983). They may also be conceptualised in terms of the World Health Organisation's International Classification of Impairments, Disabilities and Handicaps (ICIDH), which is currently undergoing major revision (Badley 1997). Impairment refers to anatomic, psychologic or physiologic abnormality and disability the resulting abnormal deficit in performance. Handicap relates to social disadvantage resulting from impairment or disability.

Use of the terms 'outcome' and 'process' varies in the literature. Zukovskis et. al. (1992), for example, interpret process measures as 'measures of disease activity' and outcome measures as 'measures of disease severity or deformity.' Traditional process measures such as laboratory tests, however, may not be particularly useful indicators of disease activity in AS (Calin 1995) while some outcome measures, such as spinal mobility, may more usefully serve as process measures. In an attempt to overcome confusion and inconsistency in the use of the words 'outcome' and 'process,' the Assessments in Ankylosing Spondylitis Working Group have coined the use of the generic word 'endpoint' (van der Heijde et. al. 1997).

The impetus for development of endpoint measurement in AS comes from a number of different sources. Firstly, AS is a chronic, progressive disease and drugs do not appear to have a significant disease modifying effect (Calin 1995). Treatments are therefore

symptomatic, and disability or handicap of prime interest. While changes in radiographs and laboratory tests may reflect disease activity in other rheumatological diseases such as rheumatoid arthritis, this is not the case in AS (Sheehan et. al. 1996, Taylor et. al. 1991). These measures are therefore generally unhelpful in assessing disease activity, outcome or prognosis in AS. A second consideration is that measurement based on questionnaires completed by patients has been shown to be more reliable and sensitive than medical tests (Calin 1995). These measures can be quick, inexpensive and easy to administer, while simultaneously fulfilling fundamental requirements such as validity, reliability, sensitivity and applicability. Such measures are also compatible with the current climate of patient autonomy and the importance of psychosocial dimensions of disease. Hallmark measures such as radiographic evidence of sacroiliitis may eventually be surplanted by these multidimensional assessments.

Up to 110 variables have been used in AS research (van der Heidje 1997). Comparative evaluation of research studies in AS is therefore problematic in the absence of the universal use of core sets of standardised endpoints. It is therefore currently difficult to pool results in meta-analysis and to translate research findings to clinical practice. "New" endpoints, such as fatigue or self-efficacy, are likely to become more important as research into AS continues. No single endpoint will encompass all dimensions of disease activity, outcome or prognosis. Conversely, some endpoint measurements may overlap resulting in redundancy. Unidimensional endpoint measures are therefore increasingly considered an inappropriate approach to assessing the efficacy of treatment in AS (Abbott et. al. 1994). The last decade has seen the development of multi-dimensional measures in which several aspects of AS are resolved to one representative index (Calin et. al. 1994, Garrett et. al. 1994, Jones et al 1996). Core sets, appropriate to four settings, are currently being developed by the Assessments in Ankylosing Spondylitis Working Group for both long and short-term application. The four settings have been resolved to three; disease-controlling anti-rheumatic therapy, disease modifying anti-rheumatic drugs/physical therapy and clinical record keeping. Preliminary efforts are to be directed at single measures, though later comparision with more recent multi-dimensional measures is anticipated (van der Heijde et. al. 1997).

1.15.2 Criteria for assessments

There is general consensus concerning the criteria that paper and instrumental measurements must fulfill in order to be considered useful endpoint measures in clinical and research settings (Calin 1995, Bellamy 1998). In addition to satisfying requirements of validity, reliability and sensitivity, assessments should ideally be quick to administer or apply, inexpensive, independent of expert intervention, and also satisfy statistical criteria. Bellamy (1998) also argues that measurements must be ethical and that potential benefits should be assessed against risk.

1.15.2.1 Validity

Validity concerns the extent to which an instrument measures what it purports to measure. The four main types of validity are face, content, construct and criterion. Face validity (credibility) relates to whether the measure is deemed by experts to include at least part of the defined attribute. To achieve face validity multi-dimensional instruments should also demonstrate appropriate weighting and aggregation of components. Content validity (comprehensiveness) is the extent to which the measurement incorporates all aspects of the defined attribute (Bellamy 1998). It is usually determined by group consensus. Instruments such as the Bath AS Metrology Index (Jenkinson et. al. 1994) and preliminary core sets of endpoints proposed by Van der Heijde et. al. (1997) appear to have good content validity and have been developed using extensive consultation with all interested parties such as patients and medical personnel. Construct validity is subdivided into convergent and discriminant. Convergent validity is claimed when there is a good positive correlation between similar measures of the same attribute. Discriminant validity relates to the correlation between two separate measures of the same attribute and between these measures and other health dimensions. Discriminant validity is claimed if the two similar measures correlate better with each other than other more distantly related measures. Finally, criterion validity is determined by estimating the extent to which a measure agrees with other accepted measures of the same phenomenon. However, such "gold standards" are not always available for comparsion and, where they are, may not necessarily be accurate or comprehensive estimates of its' true value.

1.15.2.2 Reliability

Reliability is the degree to which test scores are free from errors of measurement. Other similar terms are accuracy, consistency and stability (Domholdt 1993). Reliability may be compromised by variability in the patient, observer(s) or measurement instrument itself. It may be assessed by statistical tests which investigate either differences in facets of variation, or the nature of the association, between repeated measurements. Reliability is discussed more fully in Chapter 3.

1.15.2.3 Sensitivity

Sensitivity relates to responsiveness of an instrument in detecting small variations across the whole spectrum of patients and interventions. It has been described as the "quintessential part of any outcome measure" (Bellamy 1998). In practice this implies normal distribution of scores across the whole available range and the ability to measure both early and late stages of disease. Sensitive measures are potentially reversible and capable of movement in the true direction of change (Zukovskis et. al. 1992).

1.15.3 Assessment of function

Several functional indices have been used as endpoints in AS. Generic measures, such as the Sickness Impact Profile (Buerger et. al 1981), Arthritis Impact Measurement Scale (Meenan et. al. 1980), and the Stanford Health Assessment Questionnaire (HAQ) (Fries et. al. 1982) have been criticised on a number of grounds such as their lack of specificity (Calin et. al. 1994). Dimensions relating to manual dexterity, for example, are unlikely to apply to most AS patients. Several measures used to assess function, such as the Health Assessment Questionnaire for the Spondyloarthropathies (HAQ-S) (Daltroy et. al. 1990), have been developed specifically for AS (Dougados et. al. 1988, Abbott et. al. 1994, Calin et. al. 1994).

The Dougados Functional Index (Dougados et. al. 1988) provides some examples of the problems of functional indices. It consists of twenty questions and three categories of response. Although found to have good inter-rater reliability (Dougados et. al. 1988,

Moncur et. al. 1996), it has been criticised on a number of grounds including lack of sensitivity, redundancy, omission and ambiguity (Abbott et. al. 1994, Calin 1995). Calin (1995) reports that patients may find some questions difficult to answer without qualification, the use of help or aids is not taken into account and some questions relate to similar activities Conversely, Abbott et. al. (1994), criticise the index for omitting significant functional activitites, such as drinking from a glass. These authors developed an assessment based on the functional disability grouping suggested by Badley et. al. (1984) with the addition of a postural dimension. Three items were subsequently found to cause little difficulty to patients and were omitted in a revised scale - the Revised Leeds Disability Questionnaire (Abbott et. al. 1984). External validation demonstrated problems with the interpretation of categories in relation to some functional activities. Two of the four categories are 'only able to do using unusual movements or gadgets' and 'able to do with difficulty.' As the authors point out, patients do not always recognise that they are using unusual or "trick" movements to perform a task. It is also difficult to infer "improvement" on transition from the first of these categories to the second. Another difficulty is that patients' perceptions of their functional ability do not neccessarily correlate with those of trained observers (Abbott et. al. 1984, Moncur et. al. 1996). This may be for a variety of reasons, such as the denial of disability, or a less than optimal performance of an activity when carried out in an unfamiliar context or at an unusual time.

Calin et. al. (1994) have developed a new self-administered functional index - the Bath Ankylosing Spondylitis Functional Index (BASFI - Appendix I). This index has been developed in consultation with the medical team and patients. It consists of eight questions relating to specific functional activities and two concerning general ability to cope with everyday life. Each question is answered on a 10 cm visual analogue scale unmarked except for the words "easy" and "impossible" at either end. The patient places a mark across each line to indicate their response to each question. The index is obtained by taking the average of the distances (in millimetres) along the lines representing each of the ten questions. The BASFI has been shown to be valid, reliable and demonstrates good sensitivity across the whole spectrum of disease (Calin et. al. 1994). It therefore represents an improvement over previous functional indices and its utility is such that it has been translated into other languages such as Swedish (Cronstedt et. al. 1998).

1.15.4 Assessment of disease activity

The assessment of disease activity, as opposed to functional and other consequences of disease, represents a real challenge in a predominantly axial disease such as AS. The recently developed Bath Ankylosing Spondylitis Disease Activity Index (BASDAI, Appendix I) is a significant advance over previous entheseal indices which relied on a clinicians' assessment of tenderness over key entheseal points (Garrett et. al. 1994). The BASDAI is a self-administered questionnaire consisting of six questions which incorporate the key elements of disease activity; fatigue, axial and peripheral pain, tenderness and qualitative and quantitative aspects of morning stiffness. Responses are recorded on separate visual analogue scales. The mean of the two morning stiffness questions is added to the remaining four values and the overall mean is calculated as the final BASDAI score. The BASDAI has been shown to be a valid, reliable and sensitive measurement instrument which is quick to administer and user-friendly. It represents a significant improvement over the diverse multiple unidimensional measures previously used in intervention studies and is already beginning to be used in this context (Band et. al. 1997).

1.15.5 Multidimensional anthropometric measurement

Many different unidimensional approaches have been used to assess spinal range of movement and posture in AS. These, and other aspects of spinal measurement are discussed in the last section of this literature review. Many classical tests have poor or unknown reliability, validity and sensitivity and are complex and time consuming to conduct. The recent development of a composite, multidimensional metrology index, the Bath AS Metrology Index (BASMI, Appendix I) represents a refinement of the many clinical tests previously used (Jenkinson et. al. 1994, Jones et. al. 1995). The BASMI is an index consisting of five clinical measurements representative of the twenty clinical tests previously used in the assessment of patients at the Royal National Hospital for Rheumatic Diseases in Bath. The five measurements are called tragus-to-wall, lumbar flexion (modified Schober), intermalleolar, cervical rotation and lumbar side flexion, and are described fully in Appendix I. Measurements for each test are allocated to one of eleven hierachical scored categories. The metrological index is derived from the mean of the five

separate category scores. The index has been shown to be sensitive, accurate, and reliable on both an intra-and inter-observer basis (Jenkinson et. al. 1994).

1.15.6 Global assessment

The Bath Ankylosing Spondylitis Patient Global Score (BASG - Appendix I) (Jones et. al. 1996) has recently been developed as a global assessment of patient well-being. The score is derived from the mean response to two questions on the patients' perception of well-being over the previous week and six months. Pain and fatigue were found to be particularly significant in the perception of well-being. The score has been demonstrated to correlate well with the Bath Ankylosing Spondylitis Disease Activity and Functional Indices (BASDAI, BASFI) and to be a valid, reliable and sensitive measure of well-being.

The use of multidimensional indices is likely to increase in the future and to make a significant contribution to many aspects of research in AS, such as the efficacy of treatment interventions. One drawback to these indices, and many other, unidimensional anthropometricmeasurements, is that normative values do not appear to have been established. The wide variation in anthropometric measurement both within and between patients and healthy subjects makes it difficult to interpret the significance of test results particularly in cross-sectional studies involving patients with early disease progression. This deficit is currently being addressed by, as yet unpublished, normative studies on BASMI, BASFI, BASDAI and BASG scores (personal communication, Dr. Kumar, Royal National Hospital for Rheumatic Diseases, Bath, UK).

1.15.7 Radiographic assessment

Radiographic assessment of AS has traditionally been considered the "gold standard" for establishing diagnosis and disease progression. This is reflected in the New York (Bennett and Wood 1968) and modified New York (van der Linden et. al. 1984) criteria for diagnosis which incorporate radiographic assessment. Bilateral sacroiliitis is generally recognised as the hallmark of AS diagnosis. Inter and intra-rater reliability of grading of sacroiliitis from radiographs however, is variable (Calin 1996). Furthermore, longitudinal and cross sectional radiography has been shown to be inconsistent with some clinical

features of the disease (Spencer et. al. 1979). A global radiographic assessment of axial and hip involvement, the Bath Ankylosing Spondylitis Radiology Index (BASRI - Appendix I), has recently been developed (Mackay et. al. 1999). Using this index, bony changes in the cervical and lumbar spine, sacro-iliac joints and hips are scored on a five point severity scale from antero-posterior and/or lateral radiographs. The score has been demonstrated to have good intra- and inter-rater reliability and to be sensitive to change over a two year period. A good correlation has been reported between the Bath AS Metrology Index and the BASRI. Individual components of the BASMI, namely tragus-to-wall measurement, cervical rotation, modified Schober and lumbar side flexion, also correlated well with their corresponding radiographic scores (Kennedy et. al. 1995, Calin 1996). Good correlation has been reported between tragus-to-wall, the modified Schober and another recent radiographic scoring method for the lumbar spine (Averns et. al. 1996). Self administered instruments such as the BASDAI will, however, always be inherently more sensitive to clinical change than radiographic measurements. This, and the invasive nature of radiographs, may result in the substitution of traditional radiographic "gold standards" by contemporary multi-dimensional indices which demonstrate excellent utility in the clinical setting.

1.16 EFFICACY OF PHYSIOTHERAPY IN AS

1.16.1 Introduction

Physiotherapy has long been considered essential to the successful management of AS (Haslock 1998) and is outlined in most authoritative rheumatological texts. The main aims of physiotherapy are broad and encompass the maintenance and restoration of range of movement, normal posture, muscle strength, cardiovascular fitness and function together with patient education. Previous, largely unsuccessful, attempts to control disease by individual passive treatments such as bracing and bedrest have been superceded by more active group approaches to management. In addition, there is growing pressure for, and awareness of the importance of education in promoting self-efficacy and well-being in AS and other chronic, progressive diseases (Barlow et. al. 1993, Barlow and Barefoot 1996).

Until recently, evidence of the value of physiotherapy has been largely empirical and based on anecdotal experience (Gall 1994). In addition, physiotherapy is intuitively believed to

be of benefit in AS. This is perhaps best expressed by the comment that "the fast flowing river is less likely to freeze than a stagnant pond" (Calin 1995). The last decade, however, has seen an increase in the number of research studies devoted to evaluating the effect of physiotherapy treatments on AS. This has resulted in open debate on the value of classical treatments such as exercise (Swannell 1988, Clarke 1988). Tables 2 and 3 (pp. 64-66) summarise the results of in-patient, out-patient and combined studies on the efficacy of physiotherapy treatments in AS. The results of these studies are often difficult to interpret due to differences in and problems relating to, study design, treatment interventions, and outcome measures.

1.16.2 Research design

Many studies use patients as controls. These patients are, however, often themselves subject to interventions such as home exercise either by design or default and therefore experience varying levels of activity or other interventions (eg. drug therapy) during the trial period. Even in the absence of formal treatment, wide natural variations, for example, in range of movement, would appear to be inherent in AS patients. Russell et. al. (1993), for example, report a natural weekly fluctation in the range of lumbar flexion of six degrees. These natural variations in mobility may exceed the significant post-intervention changes reported in some studies. In addition, the use of matched patient controls may be inappropriate due to such variation.

Several studies report significant difficulties in recruitment, retention and compliance (Hidding et. al. 1993, Bakker et. al. 1994, Helliwell et. al. 1996) which may result in selection bias and there are relatively few longitudinal studies. Dedicated psychosocial studies of AS are in their infancy but the first of these suggest that patients with greater perceived severity, delayed diagnosis (Barlow and Barefoot 1996) and those attending self-help groups (Barlow et. al. 1993) are more likely to be exercise compliant. Unlike generalised low back pain, specific rheumatological conditions such as AS are not routinely conceptualised as chronic pain disorders (Shipley 1997). As a result no attempt appears to

TABLE 2 - SUMMARY OF AS IN-PATIENT PHYSIOTHERAPY TRIALS (English publications)

Reference	Study description	Follow-up	No.	Controls	Endpoint measures	Summary of key findings
O'Driscoll et. al. (1978)	Non-randomised, controlled study of 3 week in-patient physiotherapy course	3 months (11 patients)	25	9	Cervical mobility sagittal flex/extn, Coronal flexion/rotn	Statistically significant post-course improvement in all neck movements especially rotation (mean improvement 27.72 deg). Controls also showed significant improvement in rotation (mean 15.55 deg). Sig. improvement in lat. flexn. and rotn. at 3 month follow-up
Wordsworth et. al. (1984)	Prospective drug/in-patient physiotherapy trial (11 patients on Corticotrophin, 10 on placebo)	2 months (21 patients)	21	10	Finger-to-floor Tragus-to-wall Pain / Function Modified Schober Lumbar extn/lat flexn	Statistically significant and sustained improvement in all parameters (except cervical lat. flex.) Small post-treatment improvements in lumbar and thoracic mobility (mean difference ≤ 1.1cm). Greatest improvement in cervical movements (mean difference ≤ 8.4 deg) No drug related differences
Tomlinson et. al. (1986)	Retrospective, uncontrolled study of 3 week in-patient physiotherapy course	None	180	None	Finger-to-floor Tragus-to-wall Cervical flexion/rotn. Lung function	Statistically significant improvement in all measures. Small improvements in lumbar and thoracic mobility (mean diff. ≤0.48cm). Greatest improvement in cervical movements (mean difference ≤20.6 deg). No improvement in a minority of very stiff patients
Bulstrode et. al. (1987)	Randomised, controlled study of 3 week in-patient physiotherapy with/without daily passive hip stretches	6 months (7 patients)	27	12	Hip mobility (goniometer)	Statistically significant improvements (especially bilateral abduction: mean diff. 6.2 cm) in stretched v. non-stretched groups for all hip movements except flexion. Preliminary data suggests improvements maintained or increased over 6 months
Roberts et. al. (1989)	Retrospective study to determine sensitivity of anthropometric measurements. 3 - week in-patient course	4.6 years (mean)	52	None	Chest expansion Finger-to-floor Height Modified Schober Cervical rotation	Post-course improvement in all endpoints. Mean increase in cervical rotation of 19 deg. Height, finger-to-floor and cervical rotation deteriorate over the course of follow-up
Viitanen et. al. (1992)	Retrospective study of 3/4 week in-patient physiotherapy	None	505	None	Schober Occiput-to-wall, Finger-to-floor, Cervical rotation	Statistically significant improvement in all measures. Very small improvements in lumbar and thoracic mobility (mean difference ≤ 0.77 cm) Large improvement in cervical rotation (mean difference ≤11 deg.). 2-8% of patients worse
Viitanen et. al. (1995)	Prospective study of 3/4 week in-patient physiotherapy	15 months	141	None	Vital capacity (see above) Fitness	Statistically significant post-course improvement in all parameters. Improvements (except cervical rotation, finger-to-floor, fitness index) not maintained at follow-up
Band et. al. (1997)	Retrospective study of 2 week in-patient physiotherapy	None	236	None	BASMI,BASDAI, BASFI, BASG	Overall statistically significant mean improvement of 18-27%. Measures worse in 32%, 27%. 14% and 2% of patients for BASDAI, BASFI, BASG and BASMI respectively

TABLE 3 - SUMMARY OF AS OUT-PATIENT PHYSIOTHERAPY TRIALS (English publications)

Reference	Study design	Follow-up	No.	Controls	Endpoint measures	Summary of key findings
Allington et. al. (1988, abstract only available) (also reported in Swannell, 1988)	Prospective controlled study Out-patient supervised exercise classes v. advice only	4 monthly intervals up to 2 years	29	29 (non-physio. patients)	Spinal/peripheral joint mobility Spinal shape (spondylometer) Pain Lab. tests/X-rays	Small improvement in hip/lumbar mobility in exercise group No significant change in spinal shape Cervical movements worse
Rasmussen and Hansen (1989)	Report on long-term study of patients attending out-patient physiotherapy programme after 1-5 years of training	On-going	47	none	Tragus-to-wall Chest expansion Cervical rotation Fingertips-to-floor Schober Inter-malleolar	No significant disease progression in 18 patients measured at 5 year assessment point Statistics not published
Kraag et. al. (1990)	Randomised, controlled, age-stratified study of 4 months individual home physiotherapy v. no therapy	None	26	27 (non-physio. patients)	Fingertip-to-floor Schober Occiput-to-wall Pain (VAS) Morning stiffness Activities of Daily Living	Statistically significant improvement in finger-to-floor distance. Mean decrease 8.3 cm (exercise group), 2cm (control group). Improvement in function in treatment group
Kraag et. al. (1994)	Follow-up of above, controls and experimental group	8 months	46			Continuation of supervised home exercise programme helped to maintain finger-to-floor mobility in original experimental group
Hidding et. al. (1993a,1993b, 1994) Bakker et. al. (1994a)	Randomised, prospective study Home exercises compared with home exercises plus weekly group physiotherapy (9 months) Cost-benefit analysis of the above	None	144	72 (Home exercise only)	Thoracolumbar mmt. Chest expansion Cervical rotation Enthesopathy Index Functional Index Global Index Sickness Impact Profile HAQ-S	Both groups improved in most measures. Statistically significant improvement (mean difference 0.41 cm) in thoracolumbar mobility, fitness and global health in group therapy patients compared with home exercise only group Addition of group therapy costs an extra $409 per patient per annum

TABLE 3 cont. - SUMMARY OF OUT-PATIENT PHYSIOTHERAPY TRIALS (English publications)

Reference	Study description	Follow-up	No.	Controls	Endpoint measures	Summary of key findings
Barlow et. al. (1993)	Cross-sectional survey comparing members of a self-help group with non-members	6 months (metrologica l study - subset of 20 patients)	111:50 (members / non-members)	50 (Non-members)	Social Support Scale (SSS) Health Locus of control (MHLC) Depression Scale (CES-D) Fingertip-to-floor Tragus-to-wall Shoulder mobility	Better compliance and percieved value of exercise in self-help group Significant sustained improvement in all mobility scores in small subset. Mean improvements neck and shoulder 4.29-12.02 deg.
Russell et. al. (1993)	Prospective pre/post moderate/vigorous weekly exercise group	2-12mths. (30:23)	43	14 (non-ex patients)	Lumbar mobility (3-space Isotrak)	Small immediate post-exercise increase in extension only. Sig. loss of lumbar flex (median 5.5 deg.) and lat. flexn (median 2 deg.) in vigorous ex. group at 5-6 months ≥ 6 deg. mean natural fluctuation in mobility in non-exercise group
Barlow and Barefoot (1996)	Prospective pre/post 2 day patient education course	6 months	24	28 (matched non-course patients)	Dougados Funct. Index Depression Scale (CES-D) Self-efficacy scale	Education has significant benefits on depression and self-efficacy No difference in metrology in comparison with controls
Helliwell et. al. (1996)	Prospective pre/post Physiotherapy study In-pt (15) / Out-pt (15) Home ex. (14) Two groups of severity	2/4/6 months	44	None	Cervical rotation Chest expansion Modified Schober Pain/stiffness visual analogue scale	Significant immediate post-treatment differences in improvement between home exercise and supervised groups in pain/stiffness and cervical rotation (actual figures not given) No differences between treatment groups at 6 months Severe patients had similar improvement to less severe
Lubrano and Helliwell (1999)	Longitudinal follow-up of a cohort of the above	6 years	28		Chest expansion Cervical and lumbar mobility Revised Leeds Disability Quest.	A significant deterioration in all endpoints independent of disease duration and reported frequency of exercise

have yet been made to relate research findings on the management of chronic low back pain to AS patients.

1.16.3 Exercise interventions

A wide range of exercise interventions are used in physiotherapy studies. Exercise may be described as predominantly targeting stretching, mobilising, strengthening or general fitness but more specific details are rarely given. Band et. al. (1997), for example, report the use of eighteen different types of exercise but do not describe these in any detail. In addition, exercise may be combined with other treatment modalities such as electrotherapy, sling suspension, education and counselling and be carried out in supervised, unsupervised, group or individual settings. Some patients are offered a choice of treatments (Russell et. al. 1993, Viitanen et. al.1992) or even therapists (Hidding et. al. 1993). Changes in patient status before and after physiotherapy interventions may be attributable, at least in part, to these confounding variables, rather than exercise per se (Barlow et. al., 1993,1996).

1.16.4 Endpoint measures

Recent years have seen significant advances in the development of customised, validated, multidimensional endpoint measures for AS with high levels of specificity and sensitivity (Abbott et. al. 1994, Calin et. al. 1994, Garrett et. al. 1994, Jenkinson et. al. 1994, Jones et. al. 1996, MacKay et. al. 1999). These measures are beginning to be used in contemporary trials of physiotherapy in AS (Band et. al. 1997). Until very recently, studies tended to use many unidimensional measures some of which had poor or unknown validity and reliability (for example, Helliwell 1996, Tomlinson et. al. 1996). Studies also occasionally combined or adapted existing measures again raising questions of validity (Wordsworth et. al. 1984, Kraag et. al. 1990).

Endpoint measures may be compounded to "percentage improvement" (Viitanen et. al. 1992) which is difficult to interpret in real terms. Statistical tests such as determination of the "extent of effect" (mean change pre/post intervention divided by pre-treatment mean) may be a more appropriate way of describing data (Viitanen and Suni 1995). Using this test to assess four in-patient trials, these authors report a "marked, though varied efficacy" in

physiotherapy treatment. This approach reflects the general emphasis on statistical rather than clinical significance. Many studies report statistical significance based on a few degrees or centimetres increase in range of movement and there is no generally accepted gold standard for clinical significance. Ytterberg et. al. (1994) suggest that changes less than 5 degrees may not be clinically significant. Greater appreciation of the biomechanics of functional movement, for example, the range of hip movement required for everyday tasks such as putting on shoes (Frankel 1998) may also assist in interpreting endpoint measures. Recent developments in the validation of endpoint measures, including global indices and core sets of endpoints (Van der Heijde et. al. 1997), can be expected to greatly enhance research in treatment efficacy.

1.16.5 Physiotherapy and range of movement

Several studies have been conducted to assess the effects of physiotherapy on range of movement and other endpoints in patients with ankylosing spondylitis but these have varied greatly in terms of study design, intervention and the use of endpoint measure. This large variation in approach makes it difficult to evaluate the impact of physiotherapy on AS. However, a summary of the main findings of these studies is given in the remaining part of this section and in Tables 2 and 3 (pp. 64-66).

Intensive in-patient physiotherapy programmes conducted over periods of 2 to 4 weeks have been shown to improve spinal mobility in patients with AS (Table 2). With the exception of the cervical spine and hip joints, mean improvements in mobility tend to be small and approximately 1 cm or less. Several studies have reported large increases in cervical rotation following in-patient physiotherapy (O'Driscoll et. al. 1978, Tomlinson et. al. 1986, Viitanen et. al. 1992). In the first of these, however, a large improvement in cervical rotation was also found in normal controls over the same time period (Table 2). Only one study focused on a specific type of exercise and this found mean improvements of up 6.2 centimeters in hip mobility following in-patient physiotherapy combined with daily passive stretching of the hip muscles. Studies which followed-up patients after in-patient physiotherapy reported that some increases in mobility were maintained for periods of up to three months in the spine (O'Driscoll et. al. 1978, Wordsworth et. al. 1984) and six months in the hip (Bulstrode et. al. 1987). In the longer-term, in-patient improvements in mobility

have been shown to be sustained over a fifteen month interval (Viitanen et. al. 1995). Studies conducted over longer periods of up to six years however, reported deterioration in anthropometric measurements of mobility irrespective of formal or in-formal exercise intervention (Roberts et. al. 1989, Lubrano and Helliwell 1999).

In addition to in-patient physiotherapy, small improvements in mobility have been found in patients undertaking either regular supervised out-patient physiotherapy or an unsupervised home exercise programme (Table 3, pp.65-66). Some of these improvements have been shown to be maintained for periods of up to fifteen months (Barlow et. al. 1993, Viitanen et. al. 1995, Helliwell et. al. 1996). A recent six year follow-up of a cohort of patients from the latter of these studies however, showed a decline in anthropometric measures of mobility irrespective of initial disease duration, attendance at in-patient programmes or self-reported exercise frequency (Lubrano and Helliwell 1999). Out-patient management may be equally as effective as in-patient physiotherapy (Helliwell et. al. 1996) and this has important implications for cost-effectiveness (Bakker et. al. 1994).

Patients with advanced disease have demonstrated small increases in mobility following physiotherapy and, as with less severe patients, these improvements appear to be maintained in the short-term (Helliwell et. al. 1996). However, little or no improvement in mobility may be found in a minority of very stiff patients following in-patient physiotherapy (Tomlinson et. al. 1986). Although bony fusion is more extensive in patients with advanced disease, small improvements may be attributable to the stretching of muscles and ligaments in more mobile areas of the spine (Helliwell et. al. 1996).

1.16.6 Physiotherapy and posture

Maintenance or improvement of posture is often cited as the primary long-term goal of physiotherapy in AS (Russell et. al. 1993, Haslock 1998). Postural assessment in physiotherapy studies is usually based on secondary measures of overall height and "tragus-to-wall" or "occiput-to-wall" measurements. These latter assessments indirectly assess changes in spinal curvature by measuring the horizontal distance between the occiput or tragus of the ear and the wall behind when patients stand with their backs against the wall in a standardised starting position. The association between these linear measurements and

actual changes in spinal curvature does not appear to have been explored. Specific evaluation of the postural effects of physiotherapy interventions is difficult to determine in some, more recent, studies due to the use of endpoint measures which resolve a variety of anthropometric assessments into one representative score (Band et. al. 1997).

There is some evidence to support the efficacy of intensive in-patient physiotherapy in improving posture. Mean improvements of up to 1.03 cm in height, and 2.31 cm and 36% in tragus-to-wall measurements, have been reported (Tomlinson et. al. 1986, Viitanen et. al. 1992). Correspondingly, in a drug trial incorporating anthropometric measurements, Pearcy et. al. (1985b) found no significant changes in tragus-to-wall measurements following an in-patient exercise programme. Only one study appears to have followed-up postural measurements in patients following in-patient physiotherapy and this found that a significant mean improvement of one centrimeter in tragus-to-wall distance was maintained after a two month interval (Wordsworth et.al. 1986).

One study has assessed the effect of out-patient physiotherapy on spinal posture in AS. In this longitudinal controlled study of 29 patients, Swannell et. al. (1988), used a Buxton Spondylometer to assess spinal shape at four-monthly intervals over a two year period. A group of patients receiving out-patient physiotherapy was compared with controls who were given advice only. Both groups demonstrated equivalent postural decline over the two year period.

No specific studies on the effect of physiotherapy on spinal posture in patients with advanced AS appear to have been published. However, as with spinal mobility, there may be minimal or no improvement in postural measurements in a minority of very stiff patients (Tomlinson et. al. 1986, Roberts et. al. 1989).

In conclusion, there is some research evidence to support the efficacy of both in-and out-patient physiotherapy in improving mobility and posture in patients with AS. A strong case for the long term benefit of physiotherapy in maintaining or improving mobility and posture has, however, yet to emerge (Swannell 1988, Gall 1994, Lubrano and Helliwell 1999). Some of the benefits of physiotherapy may relate to more general effects such as improvements in global health and physical conditioning. Education, advice, supervision

and group influences are also emerging as important factors in AS management and there is a growing interest in these and other psychosocial aspects of the disease (Barlow et. al. 1993, Bakker et. al. 1994).

1.17 SUMMARY - PART II, ANKYLOSING SPONDYLITIS

Enthesopathy is a key pathological feature of ankylosing spondylitis. There have been considerable, recent, advances in the diagnosis, assessment and management of the disease. Changes in spinal posture are a clinical hallmark of AS but the underlying aetiology remains speculative and clinically unexplored. Exercise is widely considered to be vital to the successful management of AS. Evidence for this is largely empirical due to deficits in research design and endpoint measurement in many physiotherapy studies. A greater understanding of the mechanisms underpinning abnormal posture and movement in AS will enable more precise identification of the targets of exercise regimes. Recent developments in endpoint measurement should facilitate future evaluation of the efficacy of such programmes.

PART III - MEASUREMENT OF SPINAL MOVEMENT

1.18 INTRODUCTION

Spinal movement is affected early in AS and has recently been ratified by the European Spondyloarthropathy Study Group as a key dimension in a core set of endpoint measures for use in physiotherapy settings (van der Heijde 1997). Measurement of spinal mobility currently contributes to diagnosis and assessment of disease progression, treatment efficacy and prognosis both in AS and other spinal conditions. Spinal movement is highly complex. It occurs at twenty-three motion segments and has different axes of rotation at different levels (Andersson 1980, Bogduk 1998). There is coupling of movement with combined rotation and translation (shear) in the different segments. The principle rotations or primary movements are flexion/extension (transverse axis, sagittal plane), lateral bending (sagittal axis, coronal plane) and axial rotation (coronal axis, transverse plane). The majority of studies have focused on full range primary movements of the lumbar spine in the sagittal plane. Numerous measurement techniques have been developed for routine clinical use in AS and other spinal pathologies. These range from simple clinical tools such as tape measures and inclinometers, to more sophisticated multi-dimensional techniques using radiographs, video recordings and, most recently, computerised real-time tracking devices. Measurements should not only demonstrate good reliability but should also be accurate in that they truly reflect the underlying movement of the spine. Review of the literature on these aspects is often complicated by the lack of standardisation of equipment, procedures and statistical methods.

1.19 VALIDITY OF MEASUREMENTS OF SPINAL MOVEMENTS

1.19.1 Introduction

Measurements derived from radiographs are currently the accepted "gold standard" for validation of surface measurements of spinal movement. A number of techniques have been used to calculate movement from radiographs (Begg and Falconer 1949, Macrae and Wright 1969, Portek et. al. 1983, Roozmon et. al. 1993) though these may themselves be subject to small errors (Frobin et. al. 1996). A few invasive studies involving the insertion of Steinmann pins into vertebral bodies have been carried out to facilitate the accuracy of

radiographic measurements (Gregerson and Lucas 1967, Lumsden and Morris 1968). Another approach used in earlier studies was based on stereo or biplanar radiography (Stokes et. al. 1980, Pearcy et. al. 1985, Timbrewal et. al. 1985), but this is now generally considered neither ethical nor practical unless it is part of the normal management of a patient. Most current measurement techniques therefore assess spinal movement using non-invasive skin surface techniques.

1.19.2 Index measurement of spinal movement

The issue of the validity of skin surface measurement was initially raised by one of the earliest clinical tests of spinal movement - the Schober test (Schober 1937). This skin distraction technique was adapted for use in AS patients (Macrae and Wright 1969). In the modified test, a point is marked at the spinal intersection of a line joining the dimples of Venus with the subject standing in their normal upright posture. Further marks are made 10 cm above and 5 cm below this point. The subject is required to flex forward as far as possible. The relative distance between the upper and lower marks in standing versus forward flexion is determined by tape-measure and taken as a measure of lumbar flexion. Macrae and Wright (1969) originally claimed validity for the test on the basis of a linear relationship between radiographic measurement and the separation of these skin marks. Subsequent research, however, suggests that, largely because of variable skin movement, there is a poor correlation between the modified Schober test and bone position measurements obtained from radiographs (Portek et. al. 1983) or ultrasonic photographs (Salisbury and Porter 1987). No direct comparison appears to have been made between radiographs and skin distraction methods for other spinal movements such as extension and side flexion (Moll et. al. 1972).

A further tape-measured assessment of spinal movement, commonly used in AS studies, is the "finger-to-floor" test for sagittal flexion (Stokes et. al. 1988). This test requires the subject to flex in the sagittal plane, keeping the knees straight and feet on the floor, and to attempt to touch the floor with the fingers. Distance between fingers and floor is either measured using a tape measure or a vertically mounted ruler. A similar approach may also be used to assess coronal flexion (Pile et. al. 1991). The finger-to-floor test provides little information on regional spinal movement and both sagittal and coronal tests have been

shown to correlate poorly with x-ray measurements (Newton and Waddell 1991). However, measurements were not made at the same time as x-rays and this was shown to affect the results of other measurements in the study.

1.19.3 Angular measurement of spinal movement

Spinal movement has been determined from contour measurements taken with a variety of instruments such as flexible rulers and inclinometers. Flexible rulers ("flexicurves") can be moulded to the midline of the spine in preselected starting and finishing positions (usually in the sagittal plane). Spinal curvature is calculated from angular measurements derived from the intersection of tangents drawn against the curve profile at predetermined points (Tillotson and Burton 1991, Salisbury and Porter 1987). The difference between measurements in starting and finishing positions is taken as a measure of spinal mobility. Angular measurements of lumbar flexion obtained using this method, have been reported to give only reasonable accuracy in assessment of total lumbar motion (+/-11.2 degrees) compared with radiography (Stokes et. al. 1987). These latter discrepancies may be partly attributable to measurements being made on different days and in different test positions. When other workers eliminated these variables by simultaneous measurement, the flexicurve technique was found to be accurate to within 6 degrees (Tillotson and Burton 1991).

Inclinometers and goniometers have also been used to measure spinal movement. These range from simple clinical tools consisting of a weighted needle mounted in a calibrated fluid filled chamber (Loebl 1967, Salisbury and Porter 1987, Mellin 1986, Burdett et. al. 1986) to more sophisticated electronic double inclinometer (Adams et. al. 1986, Dillard et. al. 1991, Paquet et. al. 1991, Rainville et. al. 1994) or combined inclinometer/flexicurve systems (Anderson and Sweetman 1975, Boocock et. al. 1994) capable of continuous measurement. These instruments are either held manually against the spinous process at the point of measurement or secured by other means such as belt or tape fixation. Spinal curvature is determined by calculating the difference between angular readings taken at two points on the spine, for example, L1 and S1 to obtain the lumbar curvature. The difference in spinal curvature between start and finish positions gives an angular measurement of the range traversed. These calculations may be made manually or using computer software. Portek et. al. (1983) found that inclinometer and radiographic measures taken on seperate

occasions differed when comparing mean values and ranges of movement. More recent studies, which have made simultaneous measurements of lumbar curvature in the same individuals however, found good correlations when inclinometer measurements were compared with either radiographs (Newton and Waddell 1991, Saur et. al. 1996, Adams et. al. 1986) or ultrasonic photographs (Salisbury and Porter 1987). For both ethical and utilitarian reasons, the validity of the growing number of computerised movement analysis systems now available is unlikely to be directly determined by comparison with x-rays. In the current absence of substitute "gold standards," validity may be indirectly determined by comparison with previously validated, non-invasive techniques.

1.20 RELIABILITY OF MEASUREMENTS OF SPINAL MOVEMENT

1.20.1 Introduction

The reliability of a method of measurement concerns its ability to consistently provide the same results on repeated measurement. In spinal measurement, reliability usually refers to the consistency with which a range of movement can be measured using a particular technique. Many of the reliability studies on spinal movement have been conducted on simple clinical measures, such as the Schober and finger-to-floor tests, developed specifically for use in AS. Threats to reliability include random error introduced by operators, subjects and equipment. This error constitutes the "noise" which is a variable part of every measurement. For example, removal of equipment or surface markings between tests, long or short-term pathological or physiological changes (such as disc hydrosity or morning stiffness) may all affect the reliability of measurements. To assess the affect of these variables, reliability studies may be conducted by one person (intra-observer reliability), more than one person (inter-observer reliability), on the same day or during the same session (within-day) or on different days (between day or day-to-day reliability). Inter-observer reliability is particularly important in long-term conditions like AS, where the same observer is unlikely to make assessments throughout the entire course of the disease.

Comparison of reliability studies may be difficult due to variations in equipment, methodology (including study populations) and statistical approaches. In particular, direct comparison of results may not be possible due to lack of standardisation of statistical analyses. Reliability has, for example, been assessed by coefficients of variation or

reliability, inter- or intra-class correlation or by comparision of descriptive statistics. There appears to be no consensus on parameters for clinical reliability and even those for statistical reliability may vary (Currier 1984). In addition, measurements rated as statistically unreliable may, nonetheless, possess sufficient reliability to be of clinical value. Reliability is discussed more fully in Chapter 3 of this work.

1.20.2 Index measurement of spinal movement

Several studies have been conducted to assess the reliability of the modified Schober with conflicting results. The test has, for example, been found to have reasonable intra-and inter-observer reliability in healthy subjects (Macrae and Wright 1969, Merritt et. al. 1986, Gill et. al. 1988) and in patients with ankylosing spondylitis (Pile et. al. 1991). Low inter-rater reliability has, however, been reported by others (Reynolds 1975, Burdett et. al. 1986, Miller at. al. 1992). Miller et. al. (1992) used a "worst case" protocol to determine inter-rater reliability. They found "relatively low" reliability and identify sources of systematic error relating mainly to the identification and size of the dimples of Venus. Precise identification of the inter-dimple line, and therefore the marks above and below it, was compromised by large or absent dimples. The median position of the upper skin mark corresponded to the L2/3 interspace thus eliminating upper segments of the lumbar spine. Despite these limitations, the intra-observer reliability of modified Schober tests appears to be good. It also appears to be unaffected by warming-up exercises between repeated measurements in either AS patients or healthy controls (Roberts et. al. 1988).

Studies of the reliability of other spinal measurements based on skin markings have, like the Schober test, produced conflicting results. These measurements include the modified Moll tests for lateral flexion and extension (Pile et. al. 1991). The test for lateral flexion has been found to have generally poor intra-and inter-observer reliability (Reynolds 1975, Pile et. al. 1991). Similarly, the extension test which uses skin marks based on plumb-line levels (Moll 1972) has also been found to be unreliable (Reynolds 1975, Portek 1983).

Other linear measurements of spinal mobility, commonly used in AS, include finger-to-floor and occiput-to-wall measurements. Merritt et. al. (1986) report poor inter-and intra-observer reproducibility of finger-to-floor measurements of sagittal flexion. Others have,

however, found good intra-observer (Stokes et.al. 1988) or inter-observer reliability (Newton and Waddell 1991) or both (Pile et. al. 1991). Good reliability has also been reported for finger-to-floor measurements of lateral spinal flexion (Newton and Waddell 1991, Pile et. al. 1991, Jonsson et. al. 1995). Variation in results may be partly attributable to different experimental protocols and statistical methods. The reliability of protocols involving repeated finger-to-floor measurements in the same session may be compromised by the effects of warm-up (Roberts et. al. 1988, Stokes et. al. 1988). Furthermore, studies reporting good reproducibility of sagittal flexion measurements, tend to be those which use statistical methods (coefficient of reliability or intra-class correlation) which take into account inter-subject variation. Standardisation of protocols and statistical methods would therefore appear to be important for the reliability of these simple clinical tests. Regardless of reliability, the value of the finger-to-floor test for sagittal spinal flexion is limited by lack of validity through the inclusion of hip flexion.

Occiput-to-wall or tragus-to-wall measurement is commonly used in AS as an overall measure of spinal posture. Though apparently not subject to warming-up effects, this method has been shown to have good intra-observer reliability but poor inter-observer reliability (Stokes et. al. 1988). The sensitivity of this technique as a longitudinal measure of disease progression, particularly in early AS, is questionable. Clinical experience suggests that patients may experience developing deformity while maintaining consistent head-to-wall measurements.

1.20.3 Angular measurement of spinal movement

The reliability problems of linear skin measurements may be partially overcome by approaches which assess angular movement in relation to specified bony reference points. These measurements are inherently more likely to reflect true movement of underlying bone. They also appear to be less susceptible to skin movement error than tests, like the modified Schober, which are based on linear distances between arbitrary surface landmarks. Clinically, the flexicurve technique, which involves angular measurement in relation to bony landmarks, has been shown to have reasonable within-day and day-to-day intra-observer reliability (Salisbury and Porter 1987, Youdas et. al. 1995 , Tillotson and Burton 1991). No corresponding inter-observer studies appear to be reported in the literature. Although

an inexpensive clinical tool, measurements using the flexicurve are rather laborious and secondary errors may be introduced when drawing tangents against flexicurve tracings (Salisbury and Porter 1987, Stokes et. al. 1987). These errors may be compounded by calculations based on differences between measurements. In addition, unlike contemporary electronic tracking and video analysis systems, flexicurves, and other simple clinical tools can only be used to measure static spinal postures.

Several studies report good intra- or inter-observer reliability of either simple hand-held or more sophisticated computerised inclinometric measurements of lumbar flexion (Portek et. al. 1983, Adams et. al. 1986, Salisbury and Porter 1987, Newton and Waddell 1991) and side-flexion (Reynolds 1975). Inclinometric assessment of lumbar extension (Reynolds 1975, Merritt et. al. 1986, Keeley et. al. 1986, Gill et. al. 1988, Newton and Waddell 1991, Adams et. al. 1986) and trunk rotation (Boline et. al. 1992, Keeley et. al. 1986), however, appear to be less reliable. This may be related to factors such as tissue bunching under inclinometers and, in the case of extension, difficulty in maintaining end-range positions (Dilliard et. al. 1991). Inclinometric measurements of cervical rotation, common in AS assessment, may be susceptible to the effects of warming-up between repeat measurements within a testing session (Roberts et. al. 1988).

The reliability of inclinometers/goniometers partly depends on their being applied evenly at a tangent to the surface which is particularly difficult during manual clinical applications. Even application is also problematic where there are variations in contour due, for example, to skin or fat folds. Anomalies in positioning caused by such variations are potentially affected by the distance of the measurement gauge from the skin surface and the length of the base of the instrument. Since clinical calculations of movement are based on differences between measurements taken at two different points, small errors in local measurements may disproportionately affect overall range measurements.

Photograph and video techniques were originally developed to enable measurement of dynamic movement during gait. In early studies, goniometric measurements were made by hand from photographs or video stills and based on the angles between markers placed on bony reference points. Reliability was partly dependent on the position of camera and subject, choice of the video frame which marked a particular event (such as end of range),

and accuracy in locating the geometric centre of markers. Measurements of the position of peripheral joints, taken directly from video stills, have been shown to be comparable to hands-on clinical goniometry and reliable to within five degrees (Jeng et. al. 1990). However, spinal measurements are more problematic because marker positions are particularly likely to become partially or totally obscured during sagittal spinal movement. To overcome this problem, spinal movements were originally calculated from the angles between rods protruding at right angles from markers placed over the spinous processes. Although this technique was reliable (Thurston 1982), as with manual inclinometry, slight deviations in angulation of one or both rods could have a significant effect on angular measurements and this would affect accuracy. Manual measurement of coronal movements require the identification of at least three marker points in order to compute spinal curvature from which movement measures are derived. Direct measurement of regional spinal movement in the transverse plane is not possible using this two-dimensional technique.

1.21 COMPUTERISED TRACKING SYSTEMS

1.21.1 Introduction

The last decade has seen the development of computerised tracking systems which are capable of continuous angular or translational measurements of dynamic spinal movement. This has led to a growing interest in other aspects of measurement aside from the range of movement, such as acceleration, velocity and coupling of movement, in both healthy and pathologic spines. In addition, a body of previously unavailable normative data is being collated using these devices (Russell et. al. 1992, 1993, Trott et. al. 1996, Willems et. al. 1996, Adams et. al. 1999). These systems represent developments in established clinical methods such as inclinometry and video analysis, as well as new approaches such as the use of electromagnetictracking devices. Although currently used almost exclusively in research studies, these systems may become integrated into clinical practice if their value in endpoint measurement becomes established.

1.21.2 Electro-mechanical goniometers

Several commercial computerised linked inclinometer/goniometer systems have been developed. These include the OSI CA 6000 spinal motion analysis system (Orthopaedic

Systems Inc., Haywood, CA), the Lumbar Motion Monitor (Chattecx Corp., Chattanooga, TN) and the Isotechnologies B-200 (Isotechnologies, Hillsborough, NC). The Lumbar Motion Monitor has been reported to have good intra-and inter-rater reliability for measurements of movement, velocity and acceleration (Gill and Callaghan 1997). Measurements of maximal and sub-maximal spinal movement using the CA-6000 have similarly been found to be reliable and significantly less variable than clinical measurements using inclinometers or skin markings (Dopf et. al. 1994). Dilliard et. al. (1991), however, found poor reproducibility of range measurements using the Isotechnologies B-200 when compared with clinical inclinometry. These differences may be partially accounted for by variation in fixation systems used with these devices. Measurements taken using direct fixation methods have been shown to be more reliable than those using indirect belt fixation which permits movement between sensors and skin (Troke et. al. 1996).

1.21.3 Opto-electronic devices

Manual analysis of video recordings has now been largely superceded by more sophisticated two or three-dimensional techniques incorporating the automated digitization of marker positions. Examples include the Spinetrak (Motion Analysis Corp., California, USA) and the Peak 5 (Campden Instruments, Loughborough, UK) systems. These instruments often incorporate sophisticated calibration and tracking software programmes to overcome the problems of camera paralax and identification of marker positions. While greater freedom of movement is allowed in comparision with dual linked inclinometer systems, perennial problems relating to the identification of markers and accuracy of digitization remain. The extent to which the original reliability problems of simpler video techniques have been addressed by such advances has yet to be fully determined. Recent studies, however, suggest that such systems are capable of reliable measurements of spinal movement (Robinson et. al. 1993) and that variations due to marker placement deviation are not clinically significant (O'Connor et. al. 1993).

1.21.4 Electromagnetic devices

Electromagnetic tracking devices represent a further development in dynamic movement analysis. Three systems are currently available, the 3-Space Isotrak and 3-Space Fastrak

and the Flock of Birds (Polhemus, Vermont, USA). These systems consist of a source (or transmitter) which emits oscillating, low frequency, electromagnetic waves produced by a changing electrical field. The angular orientation and distance of small sensor(s) within the electromagnetic field is measured in relation to the source. Each sensor is connected to a systems electronic unit (SEU) which interfaces with a computer. A change in the position (X,Y, Z Cartesian coordinates) and orientation (azimuth, elevation and roll) of the sensors relative to the source causes a proportional change in their electrical output which is then converted to angular or linear measurements using specialist software. The 3-Space Fastrak has four sensors and is a development of the original 3-Space Isotrak which had only one. The Flock of Birds has six sensors. These systems are capable of continuous, real-time, measurements in three dimensions which can be displayed either graphically or recorded as numerical data.

Despite overcoming some of the challenges of opto-kinetic systems such as digitisation and tracking of markers, electromagnetic systems have methodological problems which relate to the use of an electromagnetic field. Metal within an electromagnetic field causes eddy currents and this distortion can affect measurements (An et. al. 1988). Experiments with the 3-Space Isotrak have, however, shown that accuracy can be maintained provided metal is restricted from the area between the sensors and the source (McGill 1997). A further consideration is that electro-magnetic waves decay over distance. The manufacturers claim an operating range of up to ten feet (Polhemus 1992) and there is a facility within the systems electronic unit for adjusting the intensity of the field with changing distance (An et. al. 1988). Despite this, empirical use of the Fastrak suggests some decline in accuracy with distance (Day et. al. 1998) and this would need to be assessed on individual equipment prior to its use. The manufacturers report that the accuracy with which the Fastrak measures a known angle is 0.15 degrees (root mean square (RMS) error). This equates with the findings of others who report accuracy within 0.2 degrees for both the Fastrak (Nelson et. al. 1995, Willems et. al. 1996) and Isotrak (Pearcy and Hindle 1989, Trott et. al. 1996) under experimental conditions.

Other considerations, unrelated to use of an electromagnetic field, concern the validity of sensors mounted on the surface of the skin in providing measurements of underlying bone movement. As discussed previously, variable skin movements may cause measurement

errors in clinical tests such as the modified Schober (Portek et. al. 1983). Similarly, skin-based flexicurve measurements of lumbar motion have been reported to demonstrate only reasonable accuracy in comparison with x-rays taken on a different occasion (Stokes et. al. 1987). However, *simultaneous* measurements of lumbar range of motion using skin-mounted electronic inclinometers and radiography showed good correlation (r = 0.91) (Adams et. al. 1986). Furthermore, measurements of lumbar range of motion taken with another skin surface device, the 3-Space Isotrak, have also been shown to provide means and ranges of values similar to those obtained from radiographs in an age-matched group of people (Dolan et. al. 1995).

Electromagnetic devices have been used in studies to assess both normative (Pearcy and Hindle 1989, Russell et. al. 1992, 1993, Dolan and Adams 1993, Hancock 1995, Nelson et. al. 1995, Trott et. al. 1996, Willems et. al. 1996, Adams et. al. 1999) and pathological (Russell et. al. 1993) aspects of spinal range of movement. They have been shown to provide reliable measurements of spinal range of movement (Adams and Dolan 1993, Hancock 1995, Nelson et. al. 1995, Trott et. al.1996). The validity and reliability of such measurements is discussed more fully in Chapter 3.

1.22 SUMMARY, PART III - MEASUREMENT OF SPINAL MOVEMENT

Spinal movement is an important endpoint measure in ankylosing spondylitis. Movements of the spine are highly complex and present a considerable challenge to measurement. Measurement techniques should be both valid and reliable. Measurements from x-rays are currently the gold-standard for validation but may be superceded by those obtained from multi-dimensional dynamic tracking devices. Clinical techniques which are based on skin distraction measurements provide useful indices of spinal movement but generally demonstrate poor validity and reliability. Clinical and electronic inclinometers provide angular measurements of spinal movement which have been shown to be valid and reliable for all spinal movements, with the exception of extension and rotation, when direct skin fixation methods are used. However, such devices are only suitable for obtaining static measurements. Contemporary tracking systems are capable of continuous, multi-dimensional, dynamic measurements of spinal movement. They have fostered a growing interest in various aspects of spinal movement in healthy subjects and patients. Electromagnetic systems overcome some of the problems of earlier measurement devices. However, methodological issues arise when using electromagnetic fields to measure movement and these need consideration when developing new experimental protocols.

AIMS AND OBJECTIVES

Pathological processes have been shown to impair proprioception in a variety of conditions in both peripheral and spinal joints (pp. 31-35). The exact nature of the mechanisms involved is highly complex, has yet to be precisely determined (pp. 20-23) and is likely to vary in different conditions and different joints.

The enthesopathy of ankylosing spondylitis may impair spinal position sense through a variety of different mechanisms. Pathological damage to spinal entheses may alter the input of spinal afferents which provide information on spinal position sense. These alterations could be quantative (ie. number and types of receptors) or qualitative (ie rate of firing) or a combination of both. Changes in input may lead to deficits in position sense via central and/or local segmental mechanisms (pp. 21, 23). As the disease progresses, the range and variety of spinal movements tends to become impoverished. This, in itself, could alter efference copy (pp. 23-24) and thus impact on the sensory-motor integration of peripheral position sense input from (damaged) spinal afferents (p. 23). Other central mechanisms may also be implicated since patients with chronic low back pain have been shown to have peripheral neurological deficits (pp.23-24). Changes in position sense may occur in AS due to secondary adaptation of the central nervous system (CNS) processing of proprioceptive input in response to chronic pain. Primary CNS changes in the processing of position sense input are, however, unlikely to cause AS. Such changes are more likely to cause or perpetuate instability and therefore degenerative pathology, rather than the inflammatory pathology of AS which is associated with the histocompatibility antigen HLA B27 (p. 23).

Deficits in spinal position sense in AS may affect patients ability to realign the spine consistently in the upright position and could therefore be a contributory factor in the classic postural deformity of the disease (pp. 51-53). The cause of this deformity is not yet established and, furthermore, there is little evidence that physiotherapy management significantly affects postural outcome in the long-term (pp.67-69). Deficits in position sense may be retrainable through specialised rehabilitation programmes which incorporate exercises designed to enhance the recruitment of proprioceptive afferents or to optimise compensatory mechanisms such as vision (pp. 36-39).

The **aim** of this thesis was to investigate the hypothesis that pathological processes in AS cause deficits in spinal position sense in patients compared to healthy controls (pp.51-53) and that these deficits are associated with the changes in spinal posture which characterise this disease.

The specific objectives of the experimental studies were:

I To develop and validate a reliable method of assessing spinal position sense suitable for use in a clinical setting

II To obtain normative data on spinal position sense in healthy subjects

III To investigate the hypothesis that pathological processes in ankylosing spondylitis cause deficits in spinal position sense by:

- comparing spinal position sense in patients and healthy controls
- examining the association between spinal position sense and disease progression endpoint measures in ankylosing spondylitis patients in both cross-sectional and longitudinal studies
- investigating the trainability of spinal position sense in AS patients with mild disease in response to an in-patient rehabilitation programme

IV To investigate the association between disease progression, spinal position sense and spinal posture by longitudinal study of AS patients with mild disease

CHAPTER 2

DEVELOPMENT OF A NEW TECHNIQUE FOR THE ASSESSMENT OF SPINAL POSITION SENSE

2.1 INTRODUCTION

Few studies have been conducted to assess spinal position sense in healthy subjects or patients with spinal pathology. Those which have been undertaken, either use indirect and unvalidated measurement techniques, or assess one region of the spine. "Direct" angular measurements of spinal movement from skin surface sensors have, however, been found to be more accurate than indirect methods. In addition, receptors subserving proprioception are not confined to individual spinal joints but are located in structures such as muscles and fascia which traverse many different joints. Position sense is not therefore not isolated to individual joints and it is also acquired within a shifting frame of reference which includes adjacent body parts (Fel'dman and Latash 1982, Matthews 1988). Techniques which incorporate "direct" angular measurement of spinal position at different regions of the spine would therefore appear to have good face validity in the asssessment of spinal position sense.

This chapter describes the experimental work undertaken to develop a new technique for the clinical assessment of spinal position sense suitable for use in both healthy subjects and patients with ankylosing spondylitis.

2.2 CHOOSING A SUITABLE MEASUREMENT DEVICE

A number of factors determined the final choice of a suitable device for the measurement of spinal position sense in addition to those mentioned in the introduction. Position sense has been shown to be accurate to within a few degrees in peripheral joints. Similar levels of accuracy have also been reported in the few spinal studies published to date (Chapter 1, p. 28). Any measurement device would therefore need to be capable of highly accurate angular measurements. A further consideration was the size, weight, and mode of attachment of sensors applied to the skin surface. Exteroceptive cues, in particular those of circumferential pressure, may in some circumstances, enhance proprioceptive accuity (Barrett et. al. 1991, Perlau et. al. 1995, Robbins et. al. 1995, Heit et. al. 1996). Suitable sensors would therefore need to be small and light and require only a limited degree of local fixation.

These important requirements led to consideration of a new tracking device, the 3-Space Fastrak (Polhemus, Colchester, VT). The 3-Space Fastrak is a 3-dimensional electromagnetic movement analysis system capable of "direct" skin surface measurements of spinal motion (Chapter 1, pp. 80-81). An earlier version of this system, the 3-Space Isotrak, has only one sensor and has been validated for use for this purpose (Pearcy and Hindle 1989, Dolan and Adams 1993). The more recent Fastrak has four sensors allowing simultaneous measurement from four different sites. These sensors were found to be smaller and lighter in comparison with a similar tracking device, the Flock of Birds (Ascension Technology Corporation, Vermont, USA), which also has multiple sensors. Fastrak sensors are 2.8 cm across at the widest point with an area of application of 1.4 square cm and a weight of approximately 9 milligrams. In comparision, Flock of Birds (Ascension Technology Corporation, Vermont, USA) sensors are 3 cm wide with an application area of 2 square cm. The electrical lead emerging from Fastrak sensors is also smaller and lighter than the Flock of Birds. Manufacturer's specifications (Polhemus 1992) cite update rates of 120 Hz for the Fastrak based on one sensor being operational, compared with 100 Hz for the Flock of Birds. However, in both cases the sampling frequency will be reduced accordingly when additional sensors are being used. Hence, in the case of the Fastrak, a maximal update rate of 30 Hz is cited when all four sensors are operational. In practice, we were only able to achieve update rates of 15 Hz with four

sensors operating. This update rate is, however, adequate for the measurement of static spinal postures during repositioning tasks.

2.3 LOCATION OF SENSORS

The choice of suitable sites for the location of the four sensors was influenced both by pathological considerations and the practicalities of attaching sensors at various spinal locations. Primary ankylosing spondylitis usually starts at the sacroiliac joints and may ascend to affect other regions of the spine. While disease progression and the location of spinal pathology varies between individuals, the lumbo-thoracic junction is a common site of involvement. The cervical spine may be affected relatively early on in a minority of patients. Consequently, attempts were made to attach sensors to these sites during pilot trials. Secure attachment of a sensor to the cervical spine was not possible since the weight of the lead tended to displace the sensor and there was no suitable adjacent site for attachment of a lead support. Secure fixation of a sensor at T1 was, however, possible provided two cradles of tape were arranged to support the sensor lead at the shoulder (Fig. 1). T1 was relatively easy to palpate and marked the upper limit of the thoracic spine. T7 was chosen as a further site because it indicated the middle of the thoracic spine and represented the mid-point of thoracic covexity. L1 and the sacrum (S2) were considered suitable sites because these are commonly affected by AS and secure fixation of sensors was possible.

Palpation of sensor sites commenced at the top of the spine and was carried out in a semi-flexed standing posture. In this position the scapulae rotated away from the spine and there was greater prominence of the spinous processes than in upright standing. The palpation technique was based on that recommended by Field (1994). The operator stood to one side of the subject and counted down the spine palpating the spinous processes with both hands. The fingertips of the lower hand gently moved up and down three or four centimetres at a time. Once palpation of a spinous process was established with the lower hand, a finger or the thumb of the upper hand was used to mark the position until the location of the next spinous process was ascertained. C7 ("vertebra prominens") and T1 are the two most prominent spines at the base of the neck. The location of T1 was verified by asking the subject to "nod" the head in the sagittal plane. T1 is the least mobile of the two spinous

processes on this movement (Palastanga et. al. 1989). The position of T7 was established by counting down from T1 in the manner described. The inferior angle of the scapula usually lies on a level with T7 in standing so the position of the T7 spinous process was also confirmed in relation to this. The position of L1 was ascertained by further palpation down the spine. The spinous process of L1 is longer than those of the preceding thoracic vertebra. The position of L1 was also confirmed by palpating upwards from the lumbosacral junction. In standing the iliac crests lie on a level with the spinous process of L4 and this was used as a further check on the location of L1. The location of the spinous process of S2 was acertained from the position of the dimples of Venus either side. Although the prominence of these dimples varies between individuals, in practice it was possible to locate them by observing the subject from the side at the level of the sacrum and confirming their position by palpation.

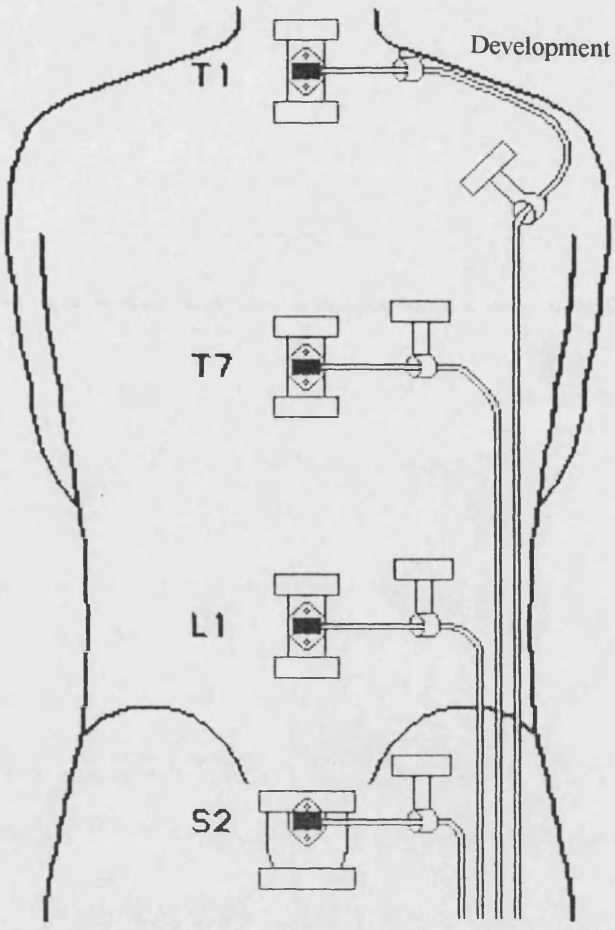
2.4 ATTACHMENT OF SENSORS

Pilot trials showed that attaching sensors with subjects in a semi-flexed position, part-way between upright standing and full flexion, limited the movement of sensors either caudally or cranially with respect to the underlying spinous process. This increased the likelihood that the flat base of the sensor remained aligned with the flat edge of the spinous process when the person either flexed further forward or stood upright and thus minimised any skin movement artefact. Inclinometers of similar size, and attached in this way, have previously been shown to measure angles which show very good correlation ($r = 0.91$) with those obtained simultaneously by x-rays (Adams et. al. 1986). Sensors were therefore applied with subjects standing in a semi-flexed position.

The midpoint of the spinous processes of T1, T7, L1 and S2 were palpated and marked to one side of the spine by a delible pencil. The skin overlying the spinous processes was cleansed by surgical spirit to allow good adhesion of the tape used to attach sensors to the skin. At the upper three sensor locations, a strip of Hypafix tape (Smith and Nephew) 5 x 1.5 cm was attached to the skin over the relevant spinous process and a strip of double-sided tape was placed over the top for attachment of the sensor. Hypafix tape has stretch and recoil properties and therefore acts during spinal movements in a manner analogous to a second skin which further reduces skin movement artefact. At T7 and L1, a perspex base

plate (2 x 1 cm) was fixed to the double-sided tape before attaching the sensor. This enabled the sensors to move freely without being impeded by the muscle mass either side. No base plate was required at T1 because it is sufficiently prominent to allow free movement of the sensor without impingement from adjacent muscle. Horizontal strips of Hypafix above and below each sensor helped to hold them securely in place during movement. At S2, a square of Hypafix was placed under a 4 x 4 cm perspex plate which provided a firm flat surface for the attachment of the sensor (Adams and Dolan 1991, Dolan and Adams 1993). Where appropriate a record was kept of any skin features to assist future placement of sensors. A previous study (Dolan and Adams 1993) has shown that aligning sensors so that their leads are supported horizontally eliminates the large systematic errors reported in earlier studies using the 3-Space Isotrak (Pearcy and Hindle 1989). Sensors were therefore positioned with their leads emerging horizontally. The weight of the leads was supported by a cradle of transpore tape sited approximately 8 cm to the right of each sensor. Figure 1 shows the method of attachment of each of the sensors.

The only way in which vertebral angles can be directly determined in a living person is from x-rays or other imaging procedures. For this reason, x-ray measures of vertebral angles are generally considered to be the "gold standard" against which the accuracy of other methods is compared. Good correlation ($r = 0.91$) has been reported between simultaneous measurements of lumbar range of motion using electronic goniometers and measurements taken from x-rays (Adams et. al. 1986). Also, measurements of lumbar range of motion obtained using an electromagnetic device, the 3-Space Isotrak, have been shown to give means and ranges of values similar to those obtained from x-rays in an age-matched group of people (Dolan et. al. 1995). The Fastrak sensors were attached in a similar manner to the inclinometers and Isotrak used previously (Adams et. al. 1986, Dolan et. al. 1995). Measurements of spinal motion should therefore reflect true angular measurements of the underlying spine. The validity of other methods of spinal measurement is discussed in Chapter 1, pp.72-75.



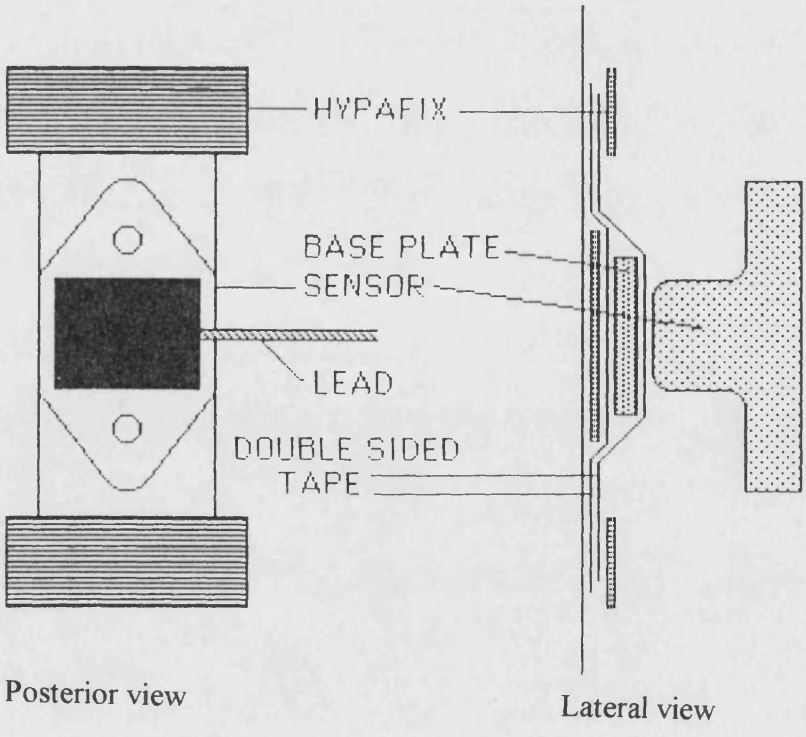


FIG. 1A (above) - Posterior view of fixation of sensors at T1, T7, L1 and S2
FIG. 1B (below) - Detail of attachment of sensors at T7 and L1 (sensor at T1 had no baseplate, sensor at S2 had larger baseplate)

2.5 CALIBRATION OF THE 3-SPACE FASTRAK

A calibration procedure was carried out to assess the accuracy and precision with which the 3-space Fastrak measures a known angle. Since electromagnetic waves decay over distance and this may affect accuracy, measurements were taken of known angles with the sensors at increasing distances from the source. During calibration procedures, sensors were positioned on a goniometer in order to simulate measurements in the sagittal and frontal planes relative to the source which was placed in a fixed location.

A calibration rig was designed in which all four sensors were attached to a goniometer mounted on a horizontal board calibrated from 0-360 degrees at one degree intervals. This rig was made of wood and plastic because metal within close proxity of the electromagnetic field may affect the accuracy of measurements (Gill et. al. 1997). At the start of the calibration procedure the sensors were placed alongside each other on the goniometer, 3 cm apart, so that the first sensor was 4.5 cm from the source (centre to centre distance) and the fourth sensor was 13.5 cm away. The arm of the goniometer was then moved at 30 degree intervals (30, 60, 90 degrees etc.) in relation to the source within the range of 0-360 degrees. Once this calibration procedure was completed, each sensor was moved along the arm of the goniometer to one of a further six positions at successively greater distances from the source. These six positions corresponded to 15.24 cm (6 inch) incremental distances from the source within the range 20.32 cm to 96.52 cm. To assess the accuracy of the Fastrak, measurements of the angular orientation and position of each sensor were taken at the starting position and all six of the subsequent distances in each of the angular positions. Calibrations were carried out with the source and sensors aligned to simulate movements in the sagittal and coronal planes. Repeat measurements were taken on a separate day to enable the precision of Fastrak measurements to be assessed. A specially designed software programme allowed measurements to be stored onto floppy disc for subsequent analysis.

2.6 CALIBRATION RESULTS

Analysis of calibration data shows that close proximity of sensors to the source, in the first position (less than 13.5 cm from the source), affects the accuracy of Fastrak measurements

in some angular positions. Figure 2 illustrates this effect for angular positions of 0, 30 and 60 degrees in sagittal flexion.

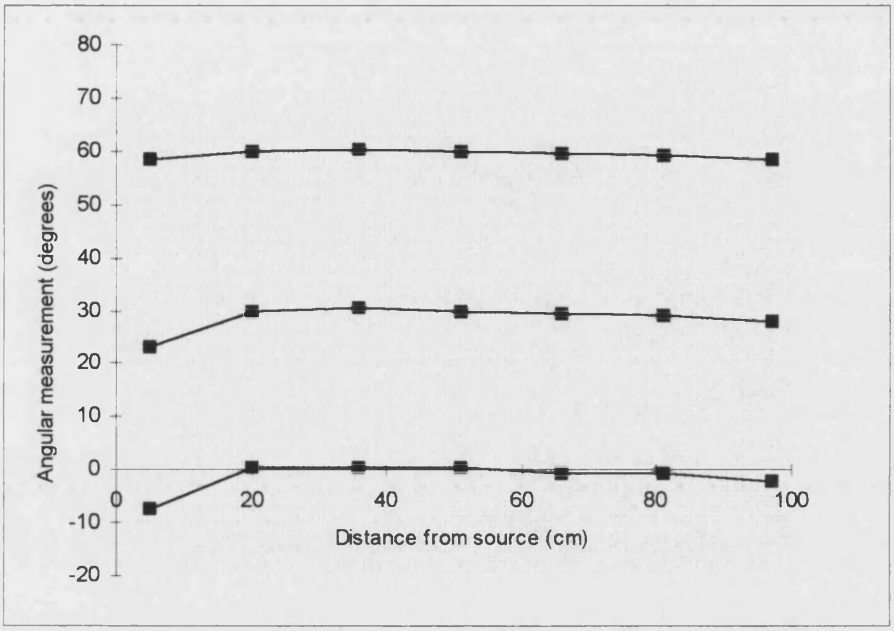


FIG. 2 - Angular measurements over distance (cm) at 0, 30, and 60 degrees of sagittal flexion (sensor 1)

The accuracy of measurements is also seen to decrease slightly as the distance between source and sensor increases. This is compatible with decay of the electromagnetic field with increasing distance from the source. When the distance between source and sensor exceeds 80 cm (position 6), accuracy of measurements appears to decline more rapidly in some positions. The optimum operating range of the Fastrak, therefore, appears to lie between positions 2-6 ie. at a distance of 20-81 cm between source and sensor (Figs. 3A/3B). The accuracy of angular measurements declines slightly from 0.29 degrees Root Mean Square (RMS) when the operational range of the sensors relative to the source is 20 cm, to 0.62 degrees RMS when this range is increased to 81 cm. The equivalent values for the coronal plane are 0.72 and 0.96 degrees. These values incorporate observer error in positioning the Fastrak sensors on the calibration goniometer and so will over-estimate the true RMS error inherent in Fastrak measurements. The slight loss in accuracy observed at greater operating distances is not associated with a comparable systematic change in precision over distance. Precision of angular measurements varies between 0.62 degrees RMS at 20 cm and 0.33

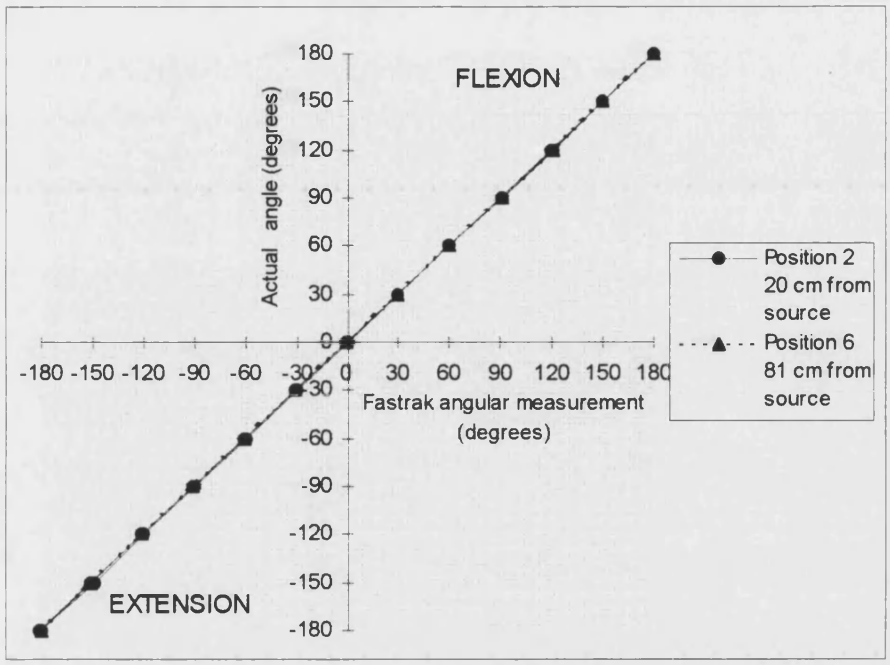


FIG. 3A - Accuracy of angular Fastrak measurements (degrees) at 20 cm and 81 cm from source. Sensor 1, sagittal plane

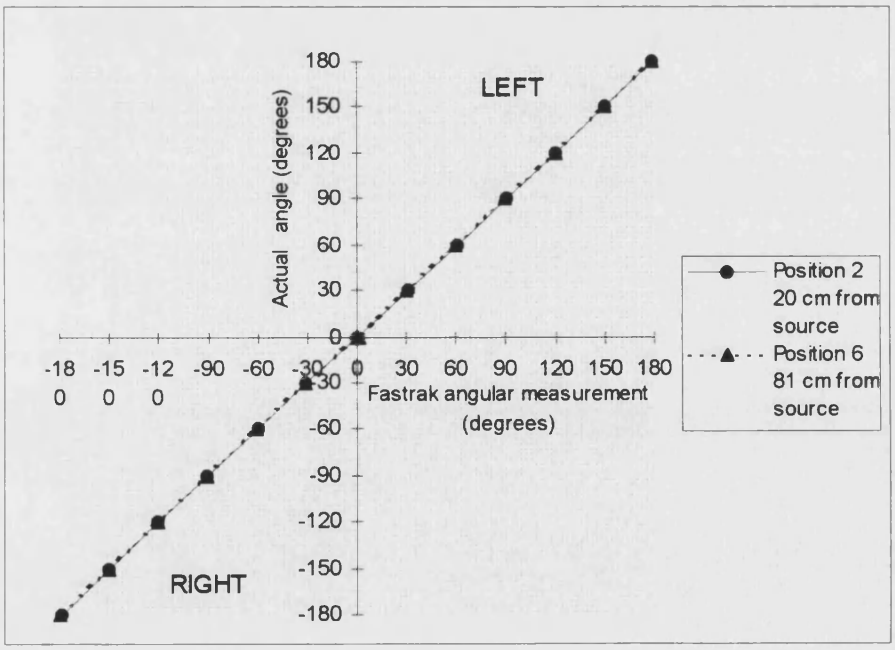


FIG. 3B - Accuracy of angular Fastrak measurements (degrees) at 20 cm and 81 cm from source. Sensor 1, coronal plane

degrees RMS at 81 cm in the sagittal plane. Equivalent values for the coronal plane are 0.63 to 0.90 degrees RMS respectively. These small and random changes in precision are therefore likely to reflect observer error in sensor positioning rather than the effect of increasing sensor-source distance.

Pilot trials showed that it was possible to maintain a 20-81 cm operating range between sensor and source under experimental conditions. The Fastrak source was mounted on a wooden stand which was placed next to subjects during testing, and its height and position were adjusted during the setting-up procedure to ensure that all sensors remained within the optimal operating range throughout the experimental protocols.

2.7 PROTOCOL TRIALS

2.7.1 Subject selection

Preliminary trials were carried out on six healthy subjects and on eight patients with ankylosing spondylitis to assess the feasibility of the proposed protocol. Healthy subjects were recruited from among staff at the University of Bristol and the Royal United Hospital, Bath. AS patients, diagnosed by the modified New York criteria (Table 1, p. 44), were recruited from among those admitted to the Royal National Hospital for Rheumatic Diseases, Bath, for intensive in-patient physiotherapy.

Patients admitted for treatment differ considerably in the severity of disease and for this reason are allocated to "fast," "moderate" or "slow" group on the basis of metrology scores (BASMI, Appendix 1). "Fast" group patients have early disease progression and must satisfy the criterion of having a mean Bath Ankylosing Spondylitis Metrology (BASMI) score of 3 or less. Other factors such as concomitant disease, age and general fitness also occasionally influence group selection so that patients in this group may sometimes have a mean BASMI slightly greater than 3. Total BASMI scores have been shown to corrrelate well with those of a validated radiographic index (Kennedy et. al. 1995). Since one of the aims of the following studies was to investigate the longitudinal effect of disease progression on spinal proprioception, it was decided to recruit patients from this group with early disease. An additional rationale for selecting this group is that patients in the

"moderate" or "slow" groups with more severe disease progression frequently have severe or complete restriction of movement in involved segments of the spine. This is reflected in high BASMI scores in those components of the index which assess mobiliity (cervical rotation, modified Schober test for sagittal lumbar flexion, coronal lumbar flexion, cervical rotation and hip abduction). When asked to flex in the sagittal plane some of these patients were observed to hold the spine as a rigid lever and pivot about the hips with very little regional spinal movement taking place. Coronal lumbar flexion in particular tended to be absent or severely limited in these patients with more advanced disease.

Although a low mean BASMI score suggests good overall range of movement, metrological assessment of the eight patients revealed that in some cases a low score masked considerable restriction of movement in one or two of the individual components of the index (Table 4). This finding reflects the many variations in the ascending pathology classically associated with primary AS. While sacroiilitis is a prevailing early feature, "skip" lesions may develop in the cervical spine or at the thoracolumbar junction thus causing earlier restriction of movement in more distal areas.

	AS SUBJECTS							
BASMI COMPONENT	**ASsz m/38**	**Asgs m/40**	**ASis m/42**	**ASaw m/39**	**ASsb f/28**	**ASnp m/40**	**ASgf m/47**	**ASmm f/40**
Tragus-to-wall :								
BASMI score	**0**	**1**	**1**	**1**	**2**	**1**	**1**	**3**
Measurement (cm)	*9.5*	10.5	*10.0*	*11.0*	13.5	*10.2*	*10.6*	*17.5*
Cervical rotation								
BASMI score	**0**	**0**	**0**	**1.5**	**1.5**	**4**	**3**	**4**
Measurement (deg.)								
- R. rotation	*95*	90	*90+*	*75*	73	*55*	*61*	*59*
- L. rotation	*90*	90	*90+*	*80*	78	*55*	*62*	*55*
Lumbar sagittal flexion								
BASMI score	**0**	**0**	**2**	**2**	**5**	**2**	**3**	**6**
Measurement (cm)	*9*	8	*6.3*	*5.7*	3.8	*6.0*	*5.0*	*3.5*
Lumbar coronal flexion								
BASMI score	**0**	**0**	**1**	**2**	**3.5**	**1.5**	**7.5**	**5**
Measurement (cm)								
- R. side flexion	21.6	26.0	*18.1*	*13.9*	12.6	*18.7*	*9.0*	*9.8*
- L. side flesion	23.9	26.0	*19.0*	*18.9*	14.7	*17.2*	*3.2*	*10.5*
Intermalleolar distance								
BASMI score	**0**	**1**	**0**	**3**	**2**	**6**	**2**	**1**
Measurement (cm)	*123*	118	*132*	*92*	106	*60*	*103*	*114*
TOTAL BASMI	**0**	**0.4**	**0.6**	**1.9**	**2.8**	**2.9**	**3.3**	**3.8**

TABLE 4 - Breakdown of metrology (BASMI) scores in eight patients allocated to a "fast" in-patient programme

Since the criterion mean BASMI of 3 or less for "Fast" group patients may mask regional limitation of mobility, it was decided to recruit patients from this group who had BASMI ratings of 3 or less on all components of the scale. These patients may be considered to have mild disease in terms of pathological and clinical progression and will be referred to as "mild" patients throughout the text. Longitudinal assessment of spinal proprioception in these patients might reasonably be supposed to have a greater capacity for change than in patients with more advanced disease. Furthermore, selection of these patients would ensure that position sense testing by an active repositioning task is less likely to be influenced by mechanical limitations due to severe local restriction in the hips or an area of the spinal complex.

2.7.2 Repositioning protocol

Pilot studies were carried out to establish an experimental protocol suitable for patients with ankylosing spondylitis and healthy controls. In peripheral joints, active position sense is classically assessed by requiring patients to match a predetermined position. This is usually indicated by the position of a contralateral limb (Stender and Drowatzky 1994, Wells et. al. 1994), by introducing some form of mechanical block at the required point in the range (Neufeld et. al. 1981) or by repeated practice attempts with verbal or visual feedback (Kiefer et. al. 1998). Spinal movements however, are far more complex than those of peripheral joints. Movements, even in very specific tasks, are highly individual, in both healthy (Russell et. al. 1992, Trott et. al. 1996, Willems et. al. 1996) and pathologic spines (Russell et. all. 1993), and also vary throughout the different regions of the spine. Everyday movements necessitate a large repertoire of spinal positions which frequently incorporate return to a starting posture which is often that of upright standing.

During feasibility studies on "fast" group patients and healthy controls it was shown that subjects understood the concept of "halfway" sagittal or coronal flexion. Furthermore, movements into these "halfway" positions incorporated localised regional movements in all areas of the spine in controls and those patients who fulfulled the study criterion of a BASMI rating of 3 or less on all components of the index (Tables 5 and 6 overleaf). These "halfway" movements were painfree in patients and therefore unlikely to provide antalgic

	Patients attending "fast" group with all BASMI components scoring less than 3				Patients attending "fast" group with some BASMI components scoring more than 3			
Angular range (degrees) traversed to "halfway"positions	**ASsz m/38**	**ASgs m/40**	**ASis m/42**	**ASaw m/39**	**ASsb f/28**	**ASnp m/40**	**ASgf m/47**	**ASmm f/40**
Total BASMI score	**0**	**0.4**	**0.6**	**1.9**	**2.8**	**2.9**	**3.3**	**3.8**
Sagittal flexion								
Thoracic spine	21.3	11.5	33.2	13.5	17.5	4.5	28.6	12.0
Lumbar spine	24.1	23.0	24.4	27.7	17.3	32.2	10.3	10.7
Hip	29.1	32.2	35.3	17.0	42.0	23.2	17.1	40.1
Right coronal flexion								
Thoracic spine	22.5	24.6	10.5	9.1	11.2	6.9	7.8	9.2
Lumbar spine	11.8	9.8	8.1	12.2	4.0	8.9	4.0	1.7
Hip	3.6	4.2	1.9	1.4	0.2	5.0	1.6	1.2
Left coronal flexion								
Thoracic spine	21.6	18.2	11.4	14.3	12.6	5.3	7.9	2.3
Lumbar spine	11.2	14.3	10.3	20.2	2.5	5.7	2.4	2.2
Hip	5.9	7.5	2.8	1.9	1.3	5.0	2.6	2.2

Table 5 - Regional angular ranges of movement traversed by AS patients to "halfway" positions in the coronal and sagittal planes

	CONTROLS					
Angular range (degrees) traversed to "halfway" positions	**CO01 (F/38)**	**CO02 (M/23)**	**CO03 (M/44)**	**CO04 (M/23)**	**CO05 (M/24)**	**CO06 (F/25)**
Sagittal flexion						
Thoracic spine	10.3	12.2	24.3	8.8	9.3	14.6
Lumbar spine	25.8	27.9	38.2	46.2	55.7	54.9
Hip	56.5	52.7	34.1	47.5	35.3	49.2
Right coronal flexion						
Thoracic spine	18.3	12.7	18.9	16.9	8.5	11.3
Lumbar spine	15.4	12.3	11.1	10.1	15.5	10.2
Hip	6.1	5.2	5.6	2.9	4.9	2.3
Left coronal flexion						
Thoracic spine	11.3	16.7	9.6	11.4	8.7	10.2
Lumbar spine	21.5	18.1	24.5	15.0	16.7	11.1
Hip	6.1	3.1	6.4	2.9	4.6	4.6

Table 6 - Regional angular ranges of movement traversed by healthy subjects to "halfway" positions in the coronal and sagittal planes

cues to spinal position sense. In addition, replication of "halfway" movements is an uncomplicated naturalistic approach to the assessment of spinal position sense and one which could be conducted easily in a clinical environment. Position sense was therefore assessed in "halfway" positions in the following studies. Changes in standing posture are a common clinical feature in ankylosing spondylitis and position sense was therefore also assessed in this position.

Patients moved spontaneously to "halfway" positions and were able to hold them without difficulty for at least five seconds before returning to the upright starting position. Angular measurements for each sensor location in "halfway" and upright positions were derived from analysis of graphic representations of the movements on a computer visual display unit (Fig. 4, p. 100). A cursor was used to locate the midpoint of the peak plateau which represented the final positions chosed by the subject. Initial overshoot, which sometimes occured in the process of returning to positions, was ignored. A single test sequence involving movement to a "halfway" position, return to upright standing and repositioning in the "halfway" position with each position, including the original starting posture, being held for 3 seconds, was timed in a group of twelve patients with mild AS. These patients were not given any time restrictions or instructions on the speed of movement and the test sequence was completed within 24 seconds. To ensure that all phases of spinal repositioning were recorded without interruption, the computer software used in these studies was designed to record for 28 seconds during each individual repositioning task.

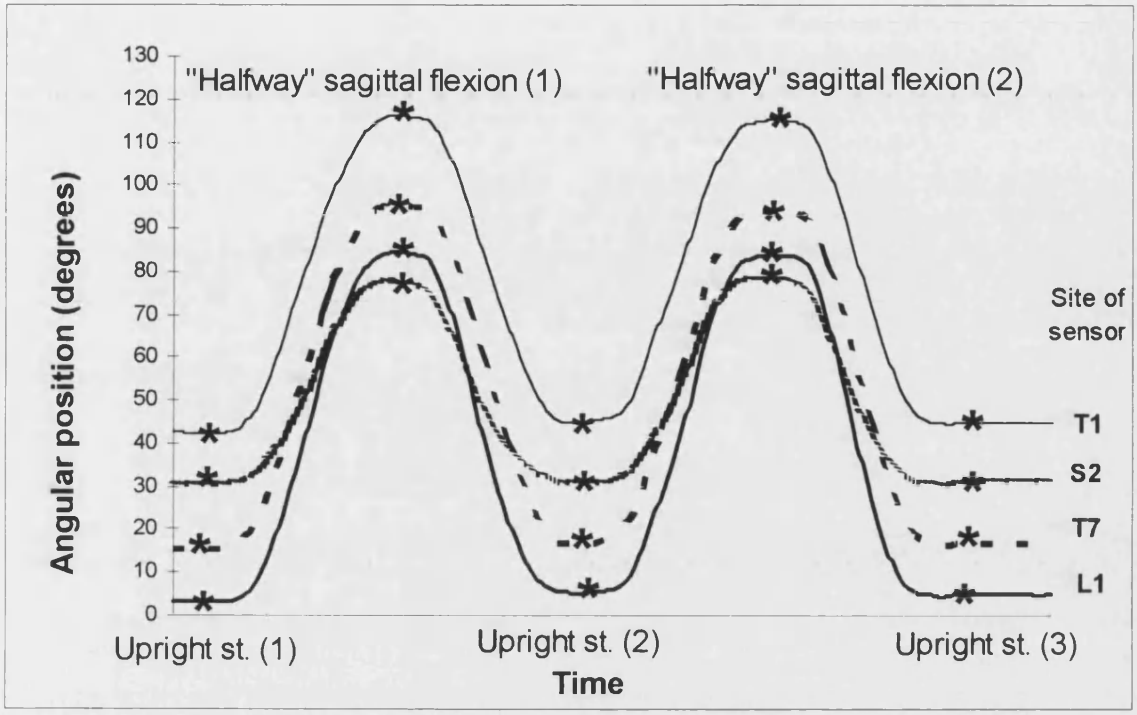


FIG. 4 - Angular measurements for each sensor location in each position taken from the midpoint of the plateau representing the final positions chosen by subjects (as indicated by asterisks)

2.8 SUMMARY

The 3-space Fastrak provides accurate angular measurements over an operating range of 20-81 cm. This range can be maintained during studies of human spinal position sense provided the position of the source is adjusted for each individual. Sensors can be securely attached to key sites of pathological interest in ankylosing spondylitis - at T1, T7, L1 and S2. Subjects understand the concept of "halfway" movements in the sagittal and coronal planes. "Halfway" movements incorporate regional spinal movement and are painfree in AS patients. Patients with mild disease and scores of 3 or less on all components of the BASMI are suitable subjects for spinal position sense assessment in ankylosing spondylitis.

CHAPTER 3

THE RELIABILITY OF THE TECHNIQUE FOR THE ASSESSMENT OF SPINAL POSITION SENSE

3.1 INTRODUCTION

3.1.1 Reliability

"Reliability" is the degree to which test scores are free from errors of measurement (Domholdt 1993). It may also be described as the extent to which a measurement or technique produces similar results on repeated measurement of individuals under different conditions (Everitt 1995). Failure to assess the reliability of a new technique makes it difficult to ascertain whether differences obtained on repeated measurements represent a real change in the subjects condition or are, in fact, attributable to other sources of variation such as experimental error. There are two basic theories of reliability which derive from either the classical or generalizability theory of measurement (Domholdt 1993). Classical measurement theory is based on the assumption that every measurement has a true component and an error component. This theory also supposes that each individual has a single true score for the measurement of interest. Generalizability theory is an extension of classical theories of reliability and one which recognises that measurements of human performance comprise not only the variable being measured ("dependant" variable) but also an error component which may consist of several different sources of variation (Domholdt 1993).

Reliability may be assessed on a "within-day" or "day-to-day" basis. To assess "within-day"reliability, repeated measurements are often undertaken in the same testing session without removing the apparatus from the subject. In this case, differences in the measured values may be due partly due to differences in performance by the subject, and partly to the measurement errors inherent in the equipment. "Day-to-day" reliability involves repeated measurements on separate days and therefore incorporates additional sources of variation for example, that associated with attaching the measuring apparatus to the subject and setting up the experimental procedure. Therefore, day-to-day variation incorporates observer error, as well as subject error and equipment error. In some cases, such as clinical studies, where measurements will be carried out by more than one person, it may be

necessary to evaluate the inter-observer reliability of a number of observers or raters, as well as the intra-observer reliability of a single observer.

3.1.2 Statistical analysis of reliability

Reliability may be quantified as either "absolute" (concordance) or "relative" (association) reliability (Domholdt 1993). Absolute reliability examines the variability between sets of repeated measurements while relative reliability assesses the relationship between them. Absolute reliability may be assessed by statistical analysis of variance (ANOVA) which looks at differences in components of variance between repeated measurements (Domholdt 1993, Munro 1997). Relative reliability is based on the concept that for a measurement to be reliable the relationship between repeated measurements should remain consistent ie. high scores should remain high and low scores remain low. It is assessed by different types of correlation coefficients. Intra-class correlation coefficients (ICCs) are a group of reliability indices that allow comparision of two or more repeated sets of measurements and (unlike inter-class correlation coefficients) are responsive to systematic errors between them. There are different formulas (Shrout and Fleiss 1979) according to experimental design but an ICC is essentially a ratio of the variability between subjects to the total variability. Two factors may therefore influence the magnitude of an ICC; either an increased variability between repeated measurements within subjects or a reduced variability of measurements between subjects. A narrow spread of scores may substantially reduce the value of the ICC (Keating and Matyas 1998). The dependance of intra-class correlation coefficients on variation between subjects makes it particularly useful at identifying those measurements most likely to distinguish between individual subjects in a group of interest (Bland and Altman 1990).

Although ICCs assess absolute as well as relative reliability they are not considered true measures of concordance (Domholdt 1993), and should therefore be supplemented by additional measures of reliability. The standard error of measurement (SEM) is a statistic used to measure absolute reliability and one which indicates how much a score is likely to vary on repeated measurements on the same subject (Denegar and Ball 1993, Domholdt 1993, Keating and Matyas 1998). The SEM is a standard deviation of measurement errors and is therefore an estimate of the precision of the measurement. It is calculated from the

ICC and has the advantage of being in the units of measurement of the scores under investigation. The 95% confidence interval around a given measurement is indicated by a value equivalent to twice the SEM either side of the measurement (Denegar and Ball 1993, Domholdt 1993). The SEM should be considered in conjunction with the ICC is deciding on the overall reliability of measurements. A relatively low ICC may be considered acceptable if the SEM suggests that inconsistency of measurement occurs in a relatively small range (Denegar and Ball 1993).

Details of the SEM and other less well known statistical tests used in this thesis are given in Appendix 3.

3.1.3 Reliability of spinal position sense measurements

The reliability of spinal position sense may be influenced by a variety of factors, including all of those outlined above. Within-subject reliability may be compromised by a variety of general factors such as learning, concentration and fatigue. Specific factors such as diurnal variations in the hydration of intervertebral discs may also influence spinal position sense measurement. Where "direct" techniques are used, reliability may be affected by error in the palpation of bony points and fixation of sensors to skin landmarks. Observer error may be compounded when, as sometimes occurs in a clinical setting, different observers are used, as mentioned above. Less direct techniques may also be associated with observer error. Goniometry, for example, requires the observer to read measurements from a recording scale. Similarly, video analysis may incorporate error due to observer identification of the geometric centre of reflective markers. Variability attributable to experimental protocols include factors such as methods of attachment of recording devices and the precise performance requirements of repositioning tasks.

Relatively few studies have been carried out to establish the reliability of peripheral or spinal position sense measurements in health or disease. Most earlier work on peripheral proprioception consists of comparative or correlational cross sectional studies carried out in the absence of any assessment of the reliability of techniques. Even long-standing and established methods, such as that frequently used to assess knee position sense (Barrack et. al. 1983), do not appear to have been assessed for reliability. Similarly, contemporary

studies of proprioception may not include an assessment of reliability even when new techniques are adopted (Beard et. a. 1993). Reliability is, however, assessed in several recent studies of spinal position sense in the lumbosacral spine (Parkhurst and Burnett 1994, Maffey-Ward et. al. 1996, Gill and Callaghan 1998, Brugmagne et. al. 1998). These studies suggest that assessment of lumbosacral position sense, by measurement of repositioning accuracy in midline postures, is reliable both on a within-day and day-to-day basis.

Parkhurst and Burnett (1994), used custom-made equipment and linear measurement techniques to assess the within-day reliability of position sense in the lower back. Subjects were moved passively to a posture approximately 5 degrees from the neutral starting position and were then required to return actively to their starting position. No significant difference was found between the results of three trials carried out on one test occasion. Maffey-Ward et. al. (1996) used the 3-Space Fastrak to assess the reliability of neutral lumbo-pelvic position sense following movements into sagittal flexion. Measurements were taken from sensors placed over the spinous processes of T10 and L1 and no significant within or between-day differences in repositioning error were found. Gill and Callaghan (1998) similarly report good day-to-day reliability of lumbar spine position sense testing in five healthy subjects and five patients with chronic low back pain. Measurements were taken using the Lumbar Motion Monitor (p. 80) at an interval of approximately twelve-weeks.

Although the methods used in these studies include components of the new technique currently under trial, for example, palpation, fixation of devices to spinous processes and repeated trials within each testing session, there are some fundamental differences to the current study. These previous studies assess position sense in midline postures in one region of the spine only. Furthermore, active or passive displacements from midline are achieved under very controlled conditions. The current, newly developed, technique however, involves the simultaneous assessment of spinal position sense at four different locations of the spine in midline and flexed positions in coronal and saggital planes under free-movement conditions. The main aim of this study, therefore, is to assess the within day and day-to-day reliability of this new method of assessing spinal position sense. A secondary aim was to obtain previously unavailable normative data on regional spinal

position sense in flexed and upright postures in healthy subjects. Ethical permission for this reliability study was obtained from the Wiltshire and Bath Health Authority.

3.2 METHODS

3.2.1 Subjects

Twenty healthy subjects gave informed consent to take part in this reproducibility study. Prior to consent, subjects were given an information sheet which outlined the general requirements of the experimental protocol (Appendix 2). Precise details of experimental method were not given at this stage. This was to prevent highly motivated subjects from either practicing or developing strategies to improve their performance prior to formal testing. Subjects were healthy employees of university or hospital departments (8 female:12 male) whose ages ranged from 23 to 52 years (mean 33.6 years). Adolescent and older subjects were excluded because of a possible maturation effect on proprioception (Jacobs et. al. 1985, Ashton-Miller et. al. 1992). This age range was also chosen to reflect the anticipated age range of ankylosing spondylitis patients in future studies. Prior to participation in the study, subjects completed a medical questionnaire to ensure that they did not meet any exclusion criteria. Exclusion criteria were based on conditions which have either been shown to affect proprioception directly or which may indirectly affect proprioception by their overall effect on motor performance. Exclusion criteria were a past or current history of:

- trauma, surgery or pathology of the spine or limbs
- diabetes or neurological disorders
- balance, hearing or visual disturbance (not corrected by glasses)
- pregnancy (within the last six months)

Three of the original volunteers were excluded because of histories of femoral fracture, back trauma and Meniere's disease respectively. A past history of backache is extremely common in the general population. An isolated, transient episode of backache not requiring medical intervention and more than five years ago was, therefore, ignored in two subjects. One of the original subjects was removed from the study because he sustained a rugby injury to the back in the two week interval between assessments. Measures were taken of

height and weight and a record made of right or left hand dominance for all subjects. Table 7 gives the physical characteristics of the remaining 20 subjects who completed the full test protocol of the study.

	AGE (yrs)	HEIGHT (m)	WEIGHT (kgs)	HAND DOMINANCE R/L
MEAN	33.6	1.72	67.8	17/3
RANGE	33-52	1.57-1.85	53.1 - 82.6	

TABLE 7 - Physical characteristics of healthy subjects in reliability study

3.2.2 Placement of Fastrak sensors and source

Subjects were asked to stand with their feet sufficiently apart to enable comfortable and safe full spinal movements in both sagittal and coronal planes. Slight variations in postural sway, which is partially dependent on proprioceptive input, have been noted in individuals in response to large changes in base of support (Kirby et. al. 1987). Distances between mid-heel and big toes were therefore recorded so that the same base of support was adopted on subsequent re-testing.

The technique used for palpation and the application of the four sensors to the spinous processes of T1, T7, L1 and S2 was as previously described (pp. 88-90). The location of the midpoint of the spinous processes of T1, T7, L1 and S2 was established by palpation down the spine with the subject in a relaxed semi-flexed position with the arms forward so that the scapulae moved away from the spine. The midpoint of the spinous processes was marked to one side by a delible pen. To facilitate adhesion of tape, the skin was wiped with surgical spirit. Small oblong strips of Hypafix tape, 5 x 1.5 cm (Smith and Nephew) were applied to the skin overlying the spinous processes of the upper three sensors. At S2, a 4 cm square piece of Hypafix was applied to the skin for attachment of the lowest sensor. A

smaller piece of double-sided tape was attached to the Hypafix for attachment of the sensor. At T7 and L1, a small perspex base plate (2 x 1 cm) was fixed to the double-sided tape before attaching the sensor. Similarly, at S2, a square of a 4 x 4 cm perspex plate was fixed to the tape to provide a firm flat surface for the attachment of the sensor (Adams and Dolan 1991, Dolan and Adams 1993). This enabled the sensors to move freely without being impeded by the muscle mass either side. Horizontal strips of Hypafix (1 x 4 cm) above and below each sensor helped to hold them securely in place during movement. Sensors where applied with their leads emerging to the right. The weight of the leads was supported by a cradle of transpore tape sited approximately 8 cm to the right of each sensor. Where appropriate a record was kept of any skin features to assist future placement of sensors.

The source was positioned on an adjustable wooden stand placed next to the subject during testing. Its height was adjusted for each subject so that the optimal operating range of 20-81 cm was maintained throughout the test procedure (Chapter 2, pp. 92-95). A record was made of the height of the source on the stand so that the same position could be adopted on subsequent retesting.

3.2.3 Experimental protocol

Subjects were assessed at least 3 hours after rising to minimize the effects of any diurnal variations in spinal mobility (Ensink et. al. 1996). No specific warm-up protocol was employed but subjects who had been sitting for long periods, for example those who had just undertaken a long car journey, were required to walk around for approximately twenty minutes prior to testing. Loose fitting shorts were worn to minimise extraneous cues from outer clothing. Similarly, all tests were carried out with arms crossed over the chest, fingertips on shoulders, to prevent subjects from determining sagittal or coronal postures by touching the front or sides of the leg with the fingertips. As previously discussed (p. 81) metal in the proximity of a magnetic field can cause changes in that field, therefore all experiments were carried out in an environment free of large metal objects in close proximity to the subject. Small metal objects, such as coins in pockets or jewellery (with the occasional exception of gold wedding rings and belly studs), were also removed from the field.

Joint position sense was measured by assessing subjects ability to actively reproduce the upright standing posture and positions in the sagittal and coronal plane. Standardised verbal instructions were given to subjects throughout the experimental protocol. At the start of the test procedure, subjects were asked to stand in a relaxed upright posture and were then instructed either to flex forward in the sagittal plane, or to flex to the right or left in the coronal plane "as far as you comfortably can." These movements were completed once each in random order and subjects were asked to return to their "exact upright starting position" on completion of each. These "full range" movements were carried out to establish the available range of movement, to ensure that subjects had adopted a stable stance for all ranges of movement and to enable subjects to gauge "halfway" positions for subsequent tests.

In the main part of the protocol, three tests were performed in random order for each of the movements - sagittal flexion, left coronal flexion and right coronal flexion. Randomisation was achieved by asking subjects to select, one by one, nine tickets from a box and making a record of the order of selection. Subjects were asked to move to a "halfway" position and to maintain this for three seconds before returning to their "exact upright starting posture with the whole of your spine from the top of your head to the tip of your tail bone." After a further three second interval, subjects were instructed to return to their exact previous "halfway" position before returning once again to their "exact upright posture." Care was taken not to indicate in any way observer expectations of the magnitude of "halfway" movements, for example by hand gestures or actual demonstration of spinal movement. Subjects were blindfolded for the short period of each test to prevent them from using visual cues to gauge spinal position. The blindfold was raised for the short period between each of the nine tests. Subjects were not given any feedback on their performance in position sense tests. At the end of each complete test sequence subjects were asked two open questions; "How do you think you got on ?" and "What made you think you were back in the same position ?." All subjects returned for a repeat measurement session, carried out at approximately the same time of day (+/- one hour), two weeks later. Figures 5 and 6 show the experimental set-up for position sense measurements in the sagittal and coronal plane.

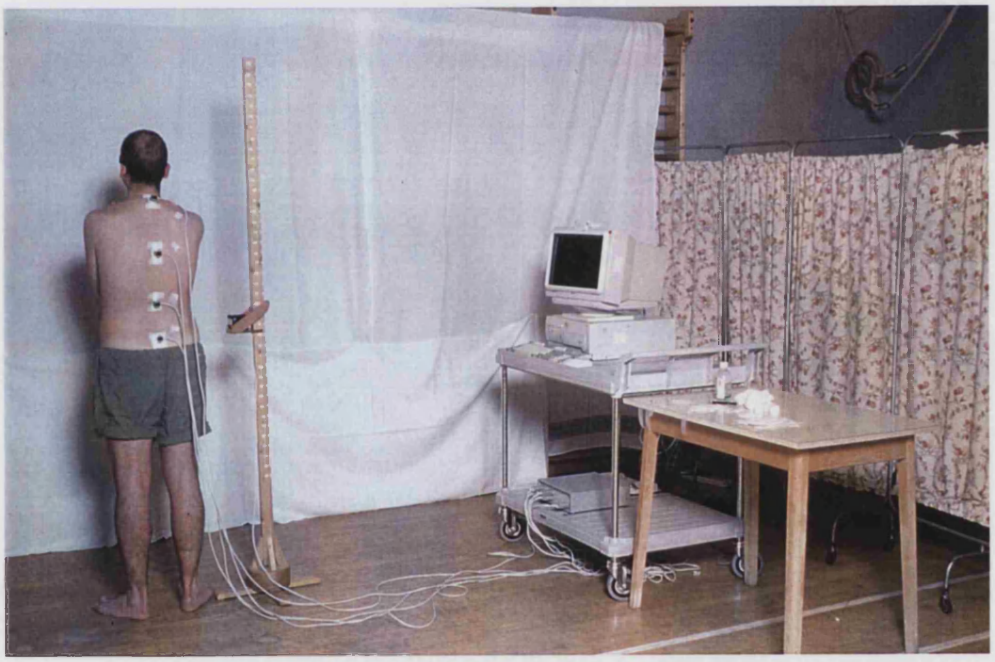


FIG. 5 - Experimental set-up for spinal position sense tests in the sagittal plane

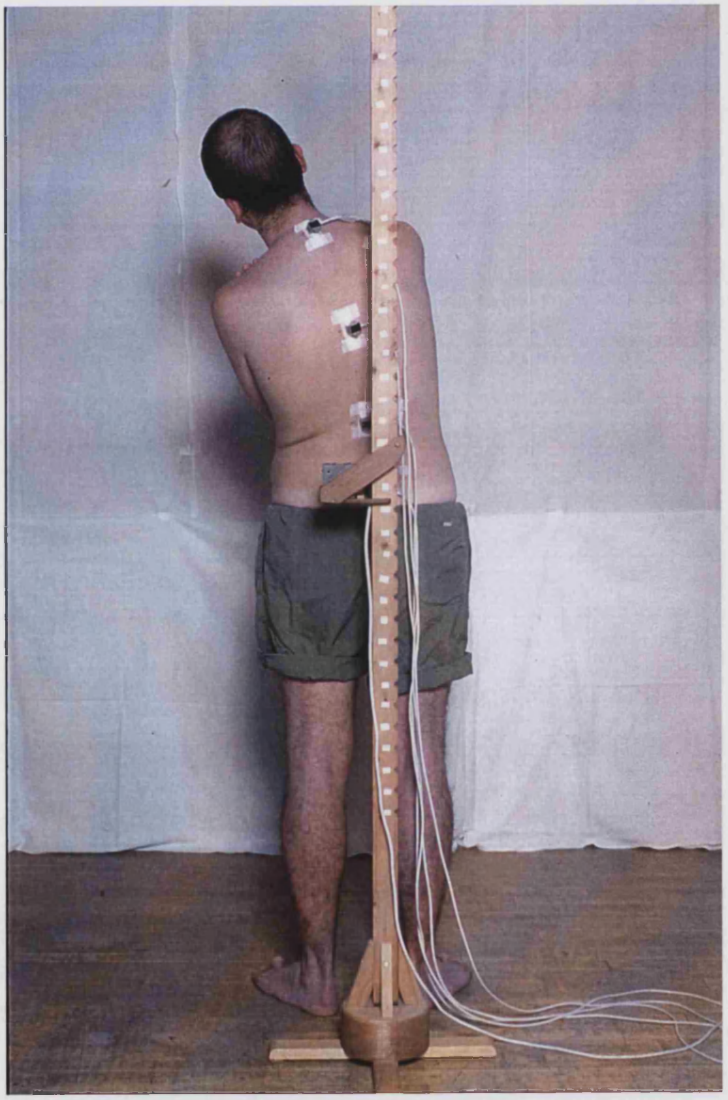


FIG. 6 - Experimental set-up for spinal position sense tests in the coronal plane

3.2.4 Determination of position sense

The absolute difference in angle between successive attempts at reproducing "halfway" positions was calculated for each sensor and used as a measure of active position sense insagittal, left and right coronal flexion. Similarly, the absolute difference between initial upright standing readings and the first return to upright standing from these movements was calculated to determine active position sense in the upright posture. The angular position of each sensor for each test was derived from analysis of graphic representations of the movements on a computer visual display unit (Fig. 4, p.100).

3.2.5 Statistical Analysis

Within-day variation in repositioning errors was analysed using single factor repeated measures analysis of variance (ANOVA) with the test as factor. Day-to-day day variation was assessed using a nested ANOVA, treating subjects as a fixed effect at the top level with sessions nested within subjects. Some data was slightly positively skewed, this was, however, exaggerated by data transformation techniques. The statistical analysis used was sufficiently robust to allow for this degree of skewednesss. As a further assessment of the the reliability of repeated measurements within and between days, the intraclass correlation coefficient (ICC, formula 2.1) was calculated. The standard error of measurement (SEM) was calculated for each sensor in each position to provide an estimate of precision and the 95% confidence limits of results. All statistical tests were two tailed and a significance level of 5% was adopted. Appendix 3 provides details of the less well known statistical tests used.

3.3 RESULTS

3.3.1 Within-day reliability of spinal position sense recordings

Mean values of active position sense for the three trials carried out on day 1 are shown in Table 8. Values ranged from 0.36 (±0.26) degrees to 6.1 (±6.04) degrees and tended to be higher in flexion than in upright standing, and at upper spinal levels compared to lower

	LOCATION OF SENSOR											
	T1			T7			L1			S2		
Test No. >	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
SAGITTAL FLEXION												
"HALFWAY"												
Mean	3.86	3.97	5.94	3.74	4.35	5.81	4.01	3.60	6.10	2.22	1.75	3.35
St. Dev.	2.55	2.93	6.17	3.17	2.80	5.71	3.38	2.87	6.04	2.04	1.03	1.65
ANOVA (p)	**0.09**			**0.13**			**0.06**			**0.006***		
UPRIGHT ST												
Mean	3.80	4.49	3.07	2.93	3.05	2.69	2.2	2.12	2.45	1.49	1.68	2.11
St. Dev.	3.13	2.47	1.84	1.82	1.22	1.91	2.03	1.53	2.49	1.23	1.57	1.80
ANOVA (p)	**0.06**			**0.70**			**0.82**			**0.36**		
R. CORONAL FLEXION												
"HALFWAY"												
Mean	3.16	2.62	3.69	2.64	1.86	3.70	1.98	1.20	1.98	0.43	0.49	0.54
St. Dev.	3.02	2.49	1.99	2.63	1.82	2.07	1.76	1.28	1.26	0.35	0.44	0.47
ANOVA (p)	**0.24**			**0.009***			**0.18**			**0.63**		
UPRIGHT ST												
Mean	1.81	2.22	2.43	2.08	2.47	2.25	1.63	1.95	1.47	0.34	0.39	0.52
St. Dev.	1.12	1.70	2.21	1.26	1.69	1.24	1.34	1.17	0.25	0.25	0.36	0.44
ANOVA (p)	**0.28**			**0.57**			**0.26**			**0.29**		
L. CORONAL FLEXION												
"HALFWAY"												
Mean	3.01	3.72	3.89	2.97	3.18	3.05	2.25	2.03	2.30	0.85	0.82	0.80
St. Dev.	2.44	3.03	2.43	2.38	2.24	1.81	2.28	1.55	1.80	0.77	0.73	0.90
ANOVA (p)	**0.53**			**0.94**			**0.84**			**0.98**		
UPRIGHT ST												
Mean	1.66	2.15	2.32	2.31	2.32	1.99	1.13	1.50	1.16	0.36	0.47	0.40
St. Dev.	0.83	1.99	1.44	1.23	1.48	1.45	0.89	1.85	1.05	0.26	0.54	0.34
ANOVA (p)	**0.24**			**0.16**			**0.23**			**0.47**		
* denotes statistical significance Results are the absolute repositioning errors in degrees quoted to two decimal places												

TABLE 8 - Within-day reliability of spinal position sense measurements in healthy subjects

spinal levels. In the majority of within-day comparisions, there was no significant difference in position sense between tests in either the sagittal or coronal planes. The exceptions to this were a significant variation for sagittal flexion at S2 ($p = 0.006$) and for right coronal flexion at T7 ($p = 0.009$). Intraclass correlation coefficients between the repeated trials carried out on day 1 are shown in Table 10. In the sagittal plane, the correlation was generally good with values lying between 0.61 and 0.70 except at S2 where lower values

were observed. In the coronal plane, values were more variable, particularly in left side flexion which represented the non-dominant side in 17 of the 20 subjects. Values in upright standing on return from right coronal flexion, however, returned consistently good ICC's ranging between 0.74-0.75 at T1-L1.

3.3.2 Day-to-day reliability of spinal position sense recordings

Average values of position sense over the three tests carried out in each position on days 1 and 2 are shown in Table 9. Day-to-day comparisions of values obtained for sagittal flexion and left and right coronal flexion revealed no significant differences in position sense within subjects. However, there was a significant difference on return to upright standing from left coronal flexion at L1 ($p=0.015$) and S2 ($p=0.002$). Figures 7A-7C illustrate the mean values of position sense for "halfway" flexed and upright positions on day 1 and day 2 in the sagittal and coronal planes.

Intraclass correlation coefficients (R) between measurements obtained on days 1 and 2 were calculated in two separate ways; by comparing individual values for each trial on each day and by comparing averaged values obtained on day 1 with those obtained on day 2. The latter comparisons provided the best correlation coefficients and these are shown in Table 10. The range and variability of the ICCs tended to reflect those obtained for the within-day trials with the values obtained in left side flexion being the lowest and most variable. The standard error of measurement (SEM) associated with the ICC is shown in Table 11. Good ICCs in upright postions at T1-L1 (return to upright standing from right coronal flexion) and T7-S2 (return to upright standing from sagittal flexion) are associated with low SEMs (less than 0.8 degrees) and therefore relatively narrow 95% confidence intervals about individual measurements (Appendix 3).

	UPRIGHT STANDING POSITIONS						"HALFWAY" POSITIONS					
Location of Sensor	**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**		**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**	
	Day 1	**Day 2**	**Day 1**	**Day 2**	**Day 1**	**Day 2**	**Day 1**	**Day 2**	**Day 1**	**Day 2**	**Day 1**	**Day 2**
T1												
Mean	3.79	3.01	2.15	1.95	2.04	1.99	4.59	5.26	3.15	3.26	3.53	3.70
St. Dev	2.56	2.65	1.73	1.60	1.28	1.48	4.25	3.53	2.53	2.59	2.63	2.62
95% C.L.	0.89	0.72	0.62	0.55	0.33	0.45	1.41	1.08	0.86	0.86	0.69	0.77
ANOVA (p)	**0.26**		**0.17**		**0.13**		**0.70**		**0.10**		**0.89**	
T7												
Mean	2.89	2.04	2.26	2.04	2.21	1.70	4.64	5.27	2.73	2.90	3.06	2.90
St. Dev	1.66	1.50	1.59	1.50	1.38	1.20	4.13	3.47	2.29	2.40	2.12	2.40
95% C.L.	0.55	0.42	0.57	0.56	0.37	0.40	1.46	1.12	0.72	0.74	0.62	0.68
ANOVA (p)	**0.25**		**0.07**		**0.12**		**0.79**		**0.54**		**0.75**	
L1												
Mean	2.25	2.52	1.68	1.72	1.26	1.80	4.57	5.17	1.72	1.86	2.19	2.15
St. Dev	2.02	1.89	1.30	1.24	1.00	1.30	4.40	4.92	1.48	1.72	1.87	1.60
95% C.L.	0.67	0.65	0.47	0.39	0.32	0.40	1.46	1.29	0.33	0.59	0.62	0.44
ANOVA (p)	**0.27**		**0.46**		**0.015***		**0.91**		**0.30**		**0.14**	
S2												
Mean	1.76	1.67	0.41	0.40	0.41	0.55	2.44	2.87	0.49	0.44	0.82	0.66
St. Dev	1.55	1.50	0.35	0.29	0.40	0.44	1.74	2.56	0.42	0.46	0.79	0.68
95% C.L.	0.47	0.42	0.08	0.09	0.11	0.15	0.46	0.70	0.13	0.14	0.18	0.17
ANOVA (p)	**0.83**		**0.44**		**0.002***		**0.22**		**0.14**		**0.98**	

* denotes statistical significance
Results are the absolute repositioning errors in degrees quoted to two decimal places
Means and standard deviations are derived from the individual results of each subject for all three tests carried out on each day

TABLE 9 - Day-to-day reliability of position sense measurements

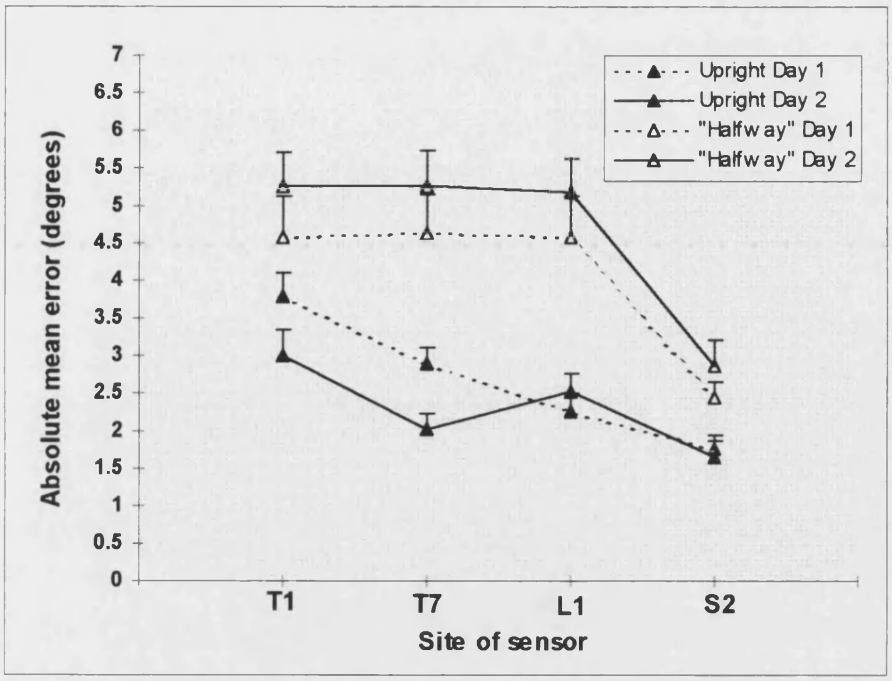


FIG. 7A - Mean repositioning errors on day 1 compared with those on day 2 for upright and flexed "halfway" positions in the *sagittal plane*. The values illustrated are the absolute re-positioning errors in degrees, averaged over three trials for each subject on each of the two testing days.

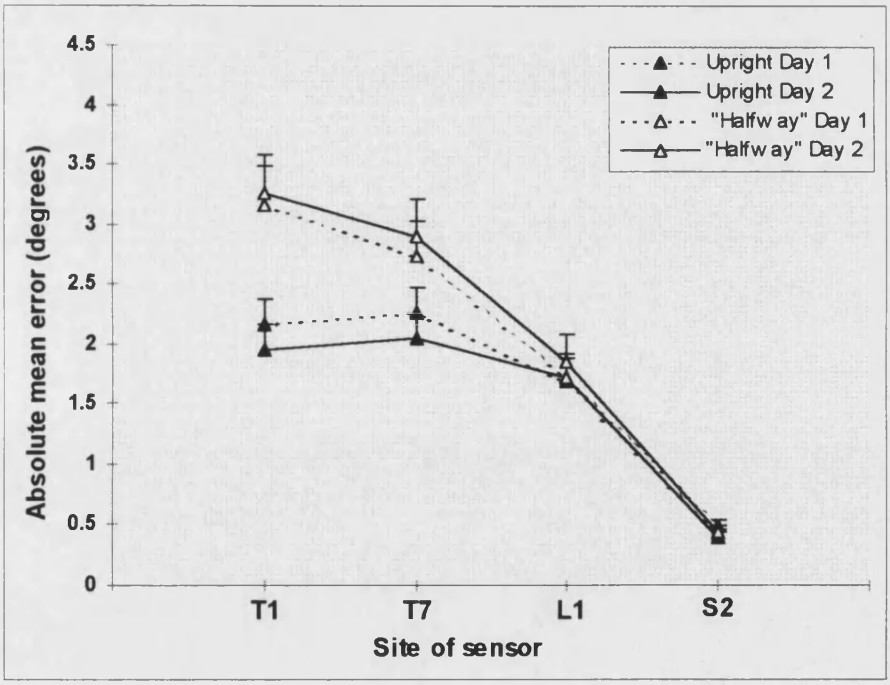


FIG. 7B - Mean repositioning errors on day 1 compared with those on day 2 for upright and flexed "halfway" positions in the *right coronal plane*. The values illustrated are the absolute re-positioning errors in degrees, averaged over three trials for each subject on each of the two testing days.

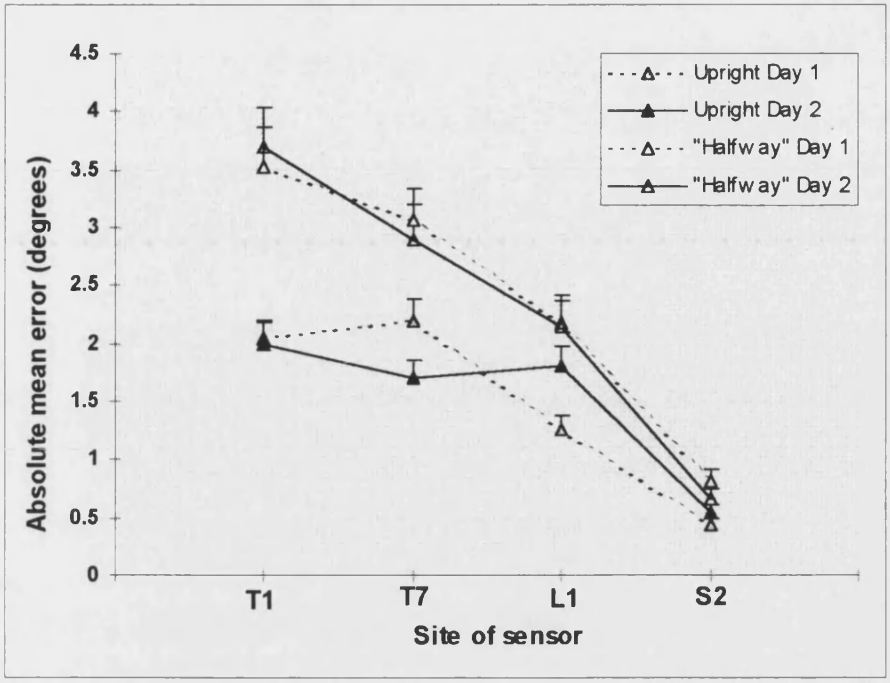


FIG. 7C - Mean repositioning errors on day 1 compared with those on day 2 for upright and flexed "halfway" positions in the *left coronal plane.* The values illustrated are the absolute re-positioning errors in degrees, averaged over three trials for each subject on each of the two testing days

	SAGITTAL FLEXION		R. CORONAL FLEXION		L. CORONAL FLEXION	
Sensor location	**Upright st.**	**"Halfway"**	**Upright st.**	**"Halfway"**	**Upright st.**	**"Halfway"**
T1						
Day 1	*R* 0.70	*R* 0.62	*R* 0.76	*R* 0.66	*R* 0.10	*R* 0.11
Day 1-2	*R* 0.57	*R* 0.79	*R* 0.76	*R* 0.68	R 0.11	*R* 0.71
T7						
Day 1	***R*** 0.61	*R* 0.64	*R* 0.74	*R* 0.52	*R* 0.68	*R* 0.38
Day 1-2	***R*** 0.57	*R* 0.83	*R* 0.78	*R* 0.67	*R* 0.26	*R* 0.66
L1						
Day 1	*R* 0.61	*R* 0.62	*R* 0.75	*R* -0.37	*R* 0.62	*R* 0.63
Day 1-2	*R* 0.72	*R* 0.90	*R* 0.72	*R* 0.43	*R* 0.26	*R* 0.34
S2						
Day 1	*R* 0.43	*R* 0.12	*R* -0.13	*R* 0.56	*R* 0.58	*R* -0.35
Day 1-2	*R* 0.72	*R* 0.39	*R* 0.43	*R* 0.43	*R* 0.29	*R* 0.66

TABLE 10 - Within-day and day-to-day (average of three tests in each position) intraclass correlation coefficients (*R*) of spinal position sense measurements in healthy subjects

	FORWARD FLEXION		RIGHT SIDE FLEXION		LEFT SIDE FLEXION	
Site of sensor	**Upright Standing**	**"Halfway"**	**Upright Standing**	**"Halfway"**	**Upright Standing**	**"Halfway"**
T1	1.20	1.28	0.64	1.08	0.84	0.89
T7	0.76	1.14	0.60	0.94	0.77	0.86
L1	0.79	1.63	0.51	0.81	0.76	0.99
S2	0.53	1.05	0.14	0.23	0.27	0.23
* Results (in degrees) are quoted to two decimal places						

TABLE 11 - Standard error of measurement (SEM) at each of the sensor sites and in each of the test positions

3.3.3 Outlying subjects

Outlying subjects were defined as those subjects who consistently had values for absolute position sense which lay more than one-and-a-half interquartile ranges from the 25th or 75th percentile and which were discrete from the main body of the data (Munro 1997, Marsh 1998). Two right-handed subjects (aged 23 and 32 years) fulfilled these criteria. These subjects had simultaneous outlying values at T1-L1 sensor sites in some tests in the coronal and sagittal planes. To assess the effect of these outlying results, data was re-analysed with these two subjects removed from the sample. The results of this re-analysis (Tables 12-15) showed no significant within-day differences in the majority of tests. As in the original data set, there was a significant within-day variation for right side flexion at T7 ($p = 0.03$) and sagittal flexion at S2 ($p = 0.035$). Similarly, there were no significant day-to-day differences in "halfway" positions. In upright postions, however, there was a significant day-to-day difference at T1 ($p = 0.025$) and S2 ($p = 0.004$) on return from left coronal flexion. Lowering the between subject variability of results by removing the two subjects from the sample reduced the day-to-day ICC's of measurements in "halfway" sagittal flexion to 0.61, 0.60, 0.66 and 0.48 at T1-S2 respectively. All other ICC's remained comparable including those on return to upright standing from the right which ranged from 0.67-0.77 at T1-L1.

	LOCATION OF SENSOR											
	T1			T7			L1			S2		
Test No. >	1	2	3	1	2	3	1	2	3	1	2	3
SAGITTAL FLEXION												
"HALFWAY"												
Mean	3.46	3.47	4.15	3.38	3.91	4.17	3.74	2.98	4.28	2.36	1.86	3.19
St. Dev.	2.33	2.44	2.90	3.13	2.59	2.76	3.29	2.28	2.35	2.11	1.03	1.54
ANOVA (p)	**0.61**			**0.62**			**0.27**			**0.035***		
UPRIGHT ST												
Mean	3.73	4.68	3.07	2.80	3.02	2.62	2.28	2.12	2.56	1.37	1.71	2.11
St. Dev.												
ANOVA (p)	**0.97**			**0.39**			**0.51**			**0.91**		
R. CORONAL FLEXION												
"HALFWAY"												
Mean	3.31	2.20	3.58	2.81	1.57	3.66	2.01	0.95	1.83	0.45	0.45	0.53
St. Dev.	3.13	2.02	2.07	2.70	1.62	2.17	1.80	0.96	1.22	0.37	0.40	0.47
ANOVA (p)	**0.52**			**0.003***			**0.08**			**0.77**		
UPRIGHT ST												
Mean	1.77	2.36	2.66	2.12	2.55	2.36	1.71	1.81	1.44	0.33	0.39	0.54
St. Dev.	1.16	1.74	2.22	1.30	1.67	1.90	1.56	1.11	1.29	0.27	0.30	0.46
ANOVA (p)	**0.09**			**0.54**			**0.45**			**0.24**		
L. CORONAL FLEXION												
"HALFWAY"												
Mean	2.97	3.60	3.93	2.79	2.99	3.11	2.22	1.81	2.07	0.86	0.79	0.72
St. Dev.	2.37	3.19	2.55	2.20	2.28	1.81	2.35	1.47	1.75	0.79	0.73	0.85
ANOVA (p)	**0.55**			**0.88**			**0.72**			**0.88**		
UPRIGHT ST												
Mean	1.66	2.30	2.08	2.33	2.51	1.81	1.12	1.47	1.11	0.36	0.51	0.43
St. Dev.	0.86	1.34	1.28	1.29	1.44	1.10	0.89	1.10	1.02	0.24	0.44	0.34
ANOVA (p)	**0.20**			**0.20**			**0.31**			**0.34**		

* denotes statistical significance
Results are the absolute repositioning errors in degrees quoted to two decimal places
Means and standard deviations are derived from the individual results of each subject for all three tests carried out on each day

TABLE 12 - Within-day reliability of position sense measurements with two outlying subjects removed from the sample

	UPRIGHT STANDING POSITIONS						"HALFWAY" POSITIONS					
Location of Sensor	**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**		**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**	
	Day 1	**Day 2**	**Day 1**	**Day 2**	**Day 1**	**Day 2**	**Day 1**	**Day 2**	**Day 1**	**Day 2**	**Day 1**	**Day 2**
T1												
Mean	3.82	2.81	2.26	1.92	2.01	1.90	3.70	4.30	3.03	3.04	3.51	3.63
St. Dev	2.57	2.05	1.76	1.58	1.19	1.40	2.54	3.29	2.49	2.49	2.71	2.61
ANOVA (p)	**0.07**		**0.12**		**0.025***		**0.55**		**0.24**		**0.89**	
T7												
Mean	2.81	1.99	2.34	1.99	2.22	1.65	3.82	4.73	2.68	2.89	2.96	2.96
St. Dev	1.64	1.54	1.62	1.49	1.29	1.22	2.80	3.02	2.33	2.45	2.07	2.45
ANOVA (p)	**0.25**		**0.08**		**0.17**		**0.38**		**0.54**		**0.74**	
L1												
Mean	2.32	2.49	1.66	1.68	1.23	1.63	3.67	4.46	1.60	1.84	2.03	2.13
St. Dev	1.59	1.97	1.32	1.25	1.00	1.20	2.68	2.75	1.42	1.76	1.86	1.68
ANOVA (p)	**0.13**		**0.13**		**0.09**		**0.40**		**0.23**		**0.18**	
S2												
Mean	1.73	1.65	0.42	0.36	0.43	0.56	2.47	2.69	0.48	0.43	0.79	0.60
St. Dev	1.62	1.49	0.37	0.28	0.35	0.45	1.68	2.62	0.41	0.47	0.78	0.46
ANOVA (p)	**0.81**		**0.50**		**0.004***		**0.61**		**0.12**		**0.89**	

* denotes statistical significance
Results are the absolute repositioning errors in degrees quoted to two decimal places

TABLE 13 - Day-to-day reliability of position sense measurements with two outlying subjects removed from the sample

	SAGITTAL FLEXION		R. CORONAL FLEXION		L. CORONAL FLEXION	
Sensor location	**Upright st.**	**"Halfway"**	**Upright st.**	**"Halfway"**	**Upright st.**	**"Halfway"**
T1						
Day 1	0.66	0.59	0.74	0.72	0.55	0.12
Day 1-2	0.47	0.61	0.77	0.65	0.03	0.69
T7						
Day 1	0.58	0.37	0.87	0.58	0.51	0.49
Day 1-2	0.55	0.60	0.67	0.69	0.34	0.69
L1						
Day 1	0.63	0.56	0.79	0.66	0.66	0.61
Day 1-2	0.74	0.66	0.73	0.40	0.38	0.22
S2						
Day 1	0.49	0.41	0.67	0.46	0.55	-0.02
Day 1-2	0.72	0.48	0.48	0.35	0.29	0.12

TABLE 14 - Within-day and day-to-day (average of three tests in each position) intraclass correlation coefficients (*R*) of position sense measurements with two outlying subjects removed from the sample

	FORWARD FLEXION		RIGHT SIDE FLEXION		LEFT SIDE FLEXION	
SITE OF SENSOR	**Upright Standing**	**"Halfway"**	**Upright Standing**	**"Halfway"**	**Upright Standing**	**"Halfway"**
T1	1.29	1.25	0.62	1.06	0.89	0.92
T7	0.78	1.29	0.77	0.93	0.72	0.83
L1	0.79	1.11	0.52	0.84	0.62	1.03
S2	0.54	1.00	0.14	0.24	0.27	0.29
* Results (in degrees) are quoted to two decimal places						

TABLE 15 - Standard error of measurement (SEM) of position sense measurements with two outlying subjects removed from the sample

3.4 DISCUSSION

3.4.1 Within-day reliability

The results of this study show that healthy volunteers were capable of reproducing spinal positions in both the sagittal and coronal planes with reasonable accuracy. Measurements made on the same day revealed no evidence of a systematic fatigue or training effect between the three repeated tests. This accords with a similar finding in a study of lower back proprioception which also involved three repeated tests of repositioning accuracy (Parkhurst and Burnett 1994).

The significant within day variations observed in "halfway" positions at two sensor locations (T7 and S2) in the present study were not seen on the second test day. Visual inspection of data for these sensors showed no systematic trend between the three tests (Table 8). These significant results were not attributable to outlying subjects since they were unaffected by removal of these subjects from the sample. Repeated "halfway" measurements in right side flexion at T7 had a reasonable ICC, suggesting that this result, may be spurious. The significant difference at S2, however, was accompanied by a low ICC, suggesting poor reproducibility at this sensor in "halfway" sagittal flexion.

3.4.2 Day-to-day reliability

Day-to-day comparisions showed that there were no significant differences in position sense measurements in most cases. The only exception to this was at L1 and S2 on return to upright standing from left side flexion. Significant differences were also found in this position at sensors T1 and S2 when the two outlying subjects were removed from the sample. These statistically significant differences, and those cited for the within-day comparisons above, may be spurious and reflect the 5% of tests which may be significant by chance when an alpha level of 0.05% is chosen. The frequency of this happening (a Type I error) increases with the number of multiple comparisons being made. For this reason, Bonferroni's correction factor is sometimes applied to the results of multiple comparisons. For the data in this reliability study this would involve dividing the alpha level of 0.05 by 24 (number of comparisons being made) to give a very much reduced level of significance for individual tests. Bonferroni's correction factor is therefore very conservative and greatly

increases the chance of a Type II error which could result in important findings being missed (Rothman 1990). For this reason it is not applied to the results of the studies in this work. An additional consideration, which relates to the results of this reliability study, is that there is nothing to suggest that the results (p values) are not from a uniform distribution and therefore not attributable to factors other than chance.

In the coronal plane, position sense measurements appeared most reliable in upright standing on return from right side flexion. In this position, good ICCs at T1-L1 (0.72-0.78) were associated with low SEMs (0.64-0.51 degrees) and therefore narrow 95% confidence limits (pp. 102-103). Return from left coronal flexion, however, was associated with a significant day-to-day difference at L1, generally poor intraclass correlation coefficients and slightly higher SEMs. The limited range of measurements at S2 resulted in low ICCs at this site (Table 10). These measurements had, however, very good precision (0.27 degrees or less). Examination of the raw data shows that the accuracy and precision of measurements at this site approached that of the 3-Space Fastrak when calibrated under laboratory conditions.

In the sagittal plane, high ICC's at T1-L1 in flexed positions were associated with SEMs of 1.63 degrees or less (Table 12). The 95% confidence limits of measurements may be assessed as twice the value of the SEM (Denegar and Ball 1993). These SEMs therefore place relatively wide confidence limits around position sense measurements at these sensors in this position. Good ICC's at T7, L1 and S2 in upright positions, however, corresponded with lower SEMs of 0.76, 0.79 and 0.53 degrees respectively. Good day-to-day reliability of lumbo-sacral repositioning in this upright posture has also been reported by other workers using the Fastrak (Maffey-Ward et. al. 1996) or Lumber Motion Monitor (Gill and Callaghan 1998). Omission of two outlying subjects reduced ICCs at T1-L1 in sagittal flexion to more modest levels (between 0.60-0.66). There was nothing to suggest that these subjects differed in any other respect from the remainder of the sample and they may represent extremes within the normal population. Their position sense values were realistic and not attributable to experimental error. There was therefore no strong justification for removing them from the sample (Gore and Altman 1982).

3.4.3 Spinal position sense - Comparison with other studies

The repositioning errors reported in this study are comparable with those reported for the knee joint (Barrack et. al. 1983, Skinner et, al. 1986, Marks et. al. 1993), cervical (Revel et. al. 1991) and lumbar spine (Brugmagne et. al. 1998, Maffey-Ward et. al. 1996). However, other investigators who measured position sense in the coronal plane in the thoracic spine report mean results at T1 between 0.9-2.5 degrees in children (Ashton-Miller et. al. 1992) and between 0.5-0.9 degrees in adults (Jacobs et. al 1985). These values are somewhat lower than those observed in the present study, and this may be explained by differences in the test conditions. In the current study, subjects were allowed to move freely in all planes and no restraining devices were used. In the latter studies, the inclusion of a restrictive strap around the pelvis (Ashton-Miller et. al. 1992) or pelvis and legs (Jacobs et. al. 1985) may have supplied valuable exteroceptive cues to movement thus making position sense errors smaller. Furthermore, these studies calculated angular displacement at T1 from linear measurements of the distance between S1 and T1. The validity of such measures has not been assessed directly but while linear measures of spinal motion have been shown to be inherently less variable than angular measures they also have a poor correlation with true angular movements of the vertebra (Portek et. al. 1983).

In this study, position sense measurements were taken from sensors placed on the skin overlying the spinous processes and angular measures were recorded directly from these sensors rather than subtended from lower levels of the spine as in some previous studies (Ashton-Miller et. al. 1992, Jacobs et. al. 1985). Results of proprioceptive studies at other levels of the spine similarly provide a difficult basis of comparison because of the use of indirect and linear measurement techniques, but they suggest greater active position sense errors commensurate with the results of this present study. Revel et. al. (1991), for example, reported an absolute mean error of 3.44 degrees for position sense in the healthy cervical spine in the sagittal and transverse planes. Recent studies on lumbar (Maffey-Ward et. al. 1996) and sacral (Brugmagne et. al. 1998) position sense in sagittal upright standing similarly report higher mean values of 2.6 degrees and 1.87 degrees respectively. These findings are in close agreement with the corresponding results of 2.39 and 1.72 degrees (mean day 1 and day 2) in the current study.

The sensors used in this study were small (1.4 cm x 2.2 cm x 2.7 cm) but nevertheless they required some fixation with adhesive tape, as described earlier. When questioned at the end of the procedure, no subject reported receiving help from exteroceptive cues or even awareness of the sensors placed on their back during testing. There is some evidence from studies on peripheral joints (Barrett et. al. 1991) and a recent study on the lumbar spine (McNair and Heine 1999) that pressure applied circumferentially by devices such as elastic bandages and braces may facilitate proprioception. However, in the present study the Hypafix tape was applied locally and directly to a small area of skin. It was also thin and stretched easily with movement thus minimising any extraneous contribution from cutaneous or subcutaneous receptors that might enhance proprioceptive acuity.

Position sense protocols frequently allow subjects to practice repositioning tasks prior to formal testing. Gill and Callaghan (1998), for example, allowed a practice trial of 10 repetitions under conditions of computerised visual feedback. Practice trials were not allowed in the current study because one of the aims was to work towards the development of a technique suitable for use with back patients in a clinical enviroment. Repeated practice of repositioning tasks in precise prespecified positions are time consuming and may exacerbate pain in patients with spinal conditions. Only one other study appears to have assessed the within-day reliability of spinal position sense. Parkhurst and Burnett (1994), using custom-made spinal motion apparatus, assessed the within-day reliability of three repeated tests of repositioning accuracy in the lower back. As in the current study, they found no evidence of learning or other systematic influences between the repeated tests of repositioning accuracy. Motor behaviour studies similarly suggest that motor tasks are dominated by visual and proprioception factors rather than cognitive ones such as practice (Adams 1981).

There was a trend for repositioning errors to increase from caudad to cephalad, particularly in coronal plane movements, and this probably reflects the increasing number of joints involved in producing the movement on ascending the spine. In forward flexion, the repositioning error at each sensor location amounted to 5-6% of the total range of movement traversed by the sensor when full range movements were performed. Position sense in this posture was the most variable and also the most likely to expose extreme values. This may reflect the fact that this posture is the only one in which the head is not

in the "eyes forward" position. Position sense in upright standing was generally superior to that in flexed positions. It is possible that the vestibular apparatus, input from which cannot be prevented, provides more help in maintaining the upright posture than it does in maintaining less commonly adopted positions. Position sense in the coronal plane was consistently better than in the sagittal plane for both upright and flexed postures. This may reflect the contribution of proprioceptive input derived from skin contact in lateral bending.

Results suggest poor reliability of position sense on return to upright postures from left side flexion. This finding may be related to side dominance because seventeen of the twenty subjects were right handed. A study of trunk positioning accuracy in children aged between 7 and 18 years, (Ashton-Miller et. al. 1992) suggests that repositioning accuracy upon returning to upright standing is better when performed from a right trunk offset. The handedness of the subjects was, however, not reported although it is likely that the majority would have been right handed, as in the general population. In the present study there was no comparable difference in position sense on return to upright standing from the right and left although there was a trend for position sense to be slightly better at the "halfway" positions when flexing to the right. Position sense measurements in upright standing on return from right coronal flexion were, however, among the most reliable of those obtained in the study. While there is no substantive evidence of a dominance effect on position sense in peripheral joints (Kokmen et. al. 1977, Kokmen 1978, Barrack et. al. 1984), the possibility of a lateral dominance effect in the spine warrants further investigation.

3.5 SUMMARY

This study demonstrated that the 3-space Fastrak provided reliable results when used to measure active position sense of the spine. Variations in position sense due to factors such as the positioning of sensors by the same operator, fatigue, and practice, did not appear to significantly affect the reliability of results within individual subjects. Averaging the absolute repositioning error of three randomised tests provided the most reliable day-to-day assessment of spinal position sense. Measurements in upright standing at T1-L1 on return from right coronal flexion and at T7, L1 and S2 on return from sagittal flexion provided the most reliable measures of position sense. The technique was sufficiently sensitive to measure variations in position sense between different regions of the spine and in different planes of movement. Repositioning errors tended to increase on ascending the spine and this probably reflected the increasing number of joints involved in producing the movement. Poor reliability of position sense on return to upright standing from the left may be the result of a lateral dominance effect which warrants further study. The position sense results of this study accord with those of other studies of position sense in both spinal and peripheral joints.

CHAPTER 4
THE EFFECT OF MAGNITUDE OF MOVEMENT ON SPINAL POSITION SENSE

4.1 INTRODUCTION

Studies of position sense classically incorporate measures to standardise the range of movement traversed in repositioning protocols. This is usually achieved by repeated practice attempts prior to formal testing (Gill and Callaghan 1997, Kiefer et. al. 1998), by mechanical blocks (Neufeld et. al. 1981), or, in peripheral joints, by using the contralateral limb to indicate target positions (Stender and Drowatzky 1994, Wells et. al. 1994). Another approach, which has been used in several studies of spinal proprioception, is to assess position sense in "neutral" midline postures following either very small (Ashton-Milleret. al. 1992, Parkhurst and Burnett 1994, Jakobs et. al. 1995) or "full" range (Maffey-Ward 1997) displacements from these. Few clinical studies of periheral position sense specifically assess the effect of range on repositioning accuracy. The results of these studies (Chapter 1, pp. 29-30) are equivocal and provide no consensus on the effects of range. No studies appear to have been conducted on the effect of range on spinal position sense.

The concept of range dependency derives from the time between the 1950's to early 1970's when joint receptors where considered predominant and the role of muscle receptors was largely unrecognised. Most neurophysiological studies conducted during this time, mainly on the articular nerves of the cat knee joint, suggested that the majority of joint receptors were most active at the extremes of flexion and extension and that relatively few were active in mid-range positions (Skoglund 1956, Burgess and Clark 1969). The importance of muscle receptors emerged in the 1970's when studies began to show that joint position sense was affected by vibration of the overlying muscles (Eklund 1972, Goodwin et. al. 1972). Parallel with this realisation was a growing recognition of the complex inter-relationship between different afferent populations. In some respects the wheel has come full circle; from Sherrington's (1900) early ideas of the 'muscular sense,' to later concepts

of the pre-eminence of joint receptors and, more recently, to a return in the recognition of the importance of muscles afferents.

Receptors subserving proprioception are now believed to be collectively capable of providing position and movement sense over the entire range of movement although the nature of the contribution from different receptor populations may vary throughout the range (Chapter 1, pp. 29-30). Recent moves away from classic proprioception protocols to more natural, self-paced, testing paradigms appear to have greater compatability with this contemporary view of proprioception and to be more suitable for use in a clinical environment. Examples are the recent adoption of closed-chain testing conditions in the lower limb (Andersen et. al. 1995, Kramer et. al. 1997) and the growing use of broader criterion test ranges rather than specific joint angles (Berenberg et. al. 1987, Field et. al. 1991). This changing approach appears particularly suitable for the clinical assessment of position sense in highly complex, multi-planar joint systems such as the spine. Spinal movement is highly variable, not only between subjects with healthy and pathologic spines (Russell et. al. 1993a, 1993b, Trott et. al. 1996, Willems et. al. 1996), but also within these subjects at different times of day (Ensink et. al. 1996) and even when apparently performing the same functional tasks (Stelmach and Diggles 1982). Precise standardisation of spinal movement is therefore very difficult to achieve even when contraining devices are used. Precise control of movements, if it were posssible, may not even be desirable since highly controlled movement may be very different from that performed under more natural conditions. In addition, constraining devices may provide extraneous cues to proprioception which are not available during normal movement. Another method devised to control spinal movement, repeated practice prior to testing (Gill and Callaghan 1998), may cause fatigue and pain in patients with spinal pathology. There is some evidence that fatigue may affect proprioception (Chapter 1, p. 31) and pain may provide antalgic cues to position sense. A further consideration is that in the spine, mechanoreceptor afferents have been isolated in the interspinous, supraspinous and flaval ligaments, thoracolumbar fascia, paraspinal muscles, lumbar intervertebral discs and cervical facet joints (Amonoo-Kuoufi 1982, Yahia

et. al. 1988, 1992, Yamashita et. al. 1993, McLain 1994). The diverse location of these afferents suggests the potential for proprioceptive input throughout the entire functional range of movement.

The aim of this study is to determine the effect of range of movement on spinal position sense during natural, self-paced movements in order to establish a clinical protocol for the assessment of position sense in normal and pathologic spines.

4.2 METHODS

4.2.1 Subjects

Twenty healthy employees of hospital or university departments (12 female: 8 male), aged 23-44 years (mean age 30.6 years) gave informed consent to take part in the study, which was approved by the local research ethics committee of the Bath and Wiltshire Health Authority. Subjects were screened to exclude current or previous conditions that may affect proprioception. These include trauma or pathology of the lower limbs or spine, neurological disorders, diabetes or conditions affecting hearing, balance or vision (not corrected by glasses). Physical characteristics of height, weight and hand dominance were also recorded.

	AGE (yrs)	HEIGHT (m)	WEIGHT (kgs)	HAND DOMINANCE R/L
MEAN	30.6	1.68	67.19	17/3
RANGE	23-45	1.55-1.83	54.0-87.2	

TABLE 16 - Physical characteristics of subjects in magnitude of movement study

4.2.2 Motion Analysis

Spinal position sense was assessed using the 3-Space Fastrak, which has previously been shown to provide reliable measurements of spinal position sense (Chapter 3). The Fastrak sensors were fixed to the skin overlying the spinous processes of T1, T7, L1 and S2 using double-sided tape and Hypafix (Smith and Nephew) in the manner previously described (pp. 71-72). The Fastrak source was mounted on an adjustable wooden stand placed next to subjects during testing, and its height and position were adjusted to ensure that all sensors operated within the optimal operating range of 20-81 cm (Chapter 2, pp. 93-95). Experiments were carried out in an environment free of any large metal objects to avoid any distortion of the electromagnetic field.

4.2.3 Experimental protocol

Spinal position sense was assessed by measuring repositioning accuracy in three incrementally different positions in sagittal and coronal flexion and on return to upright standing from these movements and using a similar approach to that of the previous reliability study (Chapter 3). All subjects were tested at least three hours after rising in order to minimise the effect of diurnal variations in spinal mobility. Subjects stood with feet sufficiently apart to enable safe and comfortable full spinal movements in the sagittal and coronal plane. At the start of the procedure, subjects were requested to stand with arms folded across the chest, and to flex "as far as you comfortably can" randomly into either forward flexion or left or right side flexion keeping the knees straight and the feet flat on the ground. Having established "full" range of movement, subjects were then blindfolded and required to flex either forward, or to the left or right "one-third," "half" or "two-thirds" of the perceived "full" range. This position was held for 3 seconds after which subjects were requested to return to their "exact upright posture." After a further 3 second interval subjects were required to return to their "exact" previous flexed position. Three tests were

carried out in each range, for each movement of forward flexion or left/right side flexion - a total of 27 randomised tests.

4.2.4 Determination of position sense

Angular error in reproducing flexed and upright positions was derived from analysis of computerised graphic representations of each sensor movement for each test. The difference in angle between attempts at reproducing "one-third" "half" and "two-thirds" movements was calculated for each sensor and used as a measure of active position sense in forward, left and right side flexion. Similarly, the difference between the initial upright standing reading and the first return to upright standing from each movement was used as a measure of position sense in the upright posture. Signed differences (+/-) were used to assess undershoot or overshoot of target positions and unsigned differences to assess absolute error.

4.2.4 Determination of range

The total angular range of movement traversed by T1, T7, L1 and S2 was calculated by comparing angular measurements at these sensors at the start and finish of movements in each of the range categories. Regional angular range of movement in the upper and lower thoracic spine and the lumbar spine was assessed by determining the angular differences between T1 and T7, T7 and L1, and L1 and S2 in upright standing and subtracting these from the respective differences in flexed positions. Hip movements were assessed by determining the difference between angular measurements obtained at S2 at the start and finish of each movement.

4.2.5 Statistical analysis

Differences in range of movement and position sense within each range category were assessed using a single factor within-subject analysis of variance looking at trial within subjects. Differences in position sense between range categories was assessed using a single factor within-subject analysis of variance looking at range within subjects. The 95% confidence levels of measurements at each sensor in each position and category of magnitude were also calculated. The value of the mean plus or minus that of the confidence level indicates the parameters within which the true mean of the population lies in 95% of cases. Qualitative results were also investigated using binomial distribution tables. Post-hoc analysis was carried out using Tukey's honestly significant difference (HSD) test. Statistical tests were two-tailed and significance was accepted at the 5% level. Appendix 3 gives details of the less well known statistical tests used in this study.

4.3 RESULTS

4.3.1 Total angular and regional ranges of movement

In the majority of cases, there were no significant differences in either total angular or regional range of movement traversed by each sensor between repeated trials in each range category. Exceptions to this included a maximum difference in total range of movement of 4.12 degrees at S2 for repeated trials in "two-thirds" forward flexion. In addition, a maximum difference of 3.68 degrees in total range of movement was found at T1 for repeated trials in "half" right side flexion, which resulted in smaller significant differences in both total and regional angular right side flexion movements lower down the spine.

The total angular range of movement traversed by the four sensors in each of the range categories is shown in Figures 8A-8C. Regional angular movement between adjacent sensor locations and at the hip (S2) is shown in Table 17. An incremental increase in both

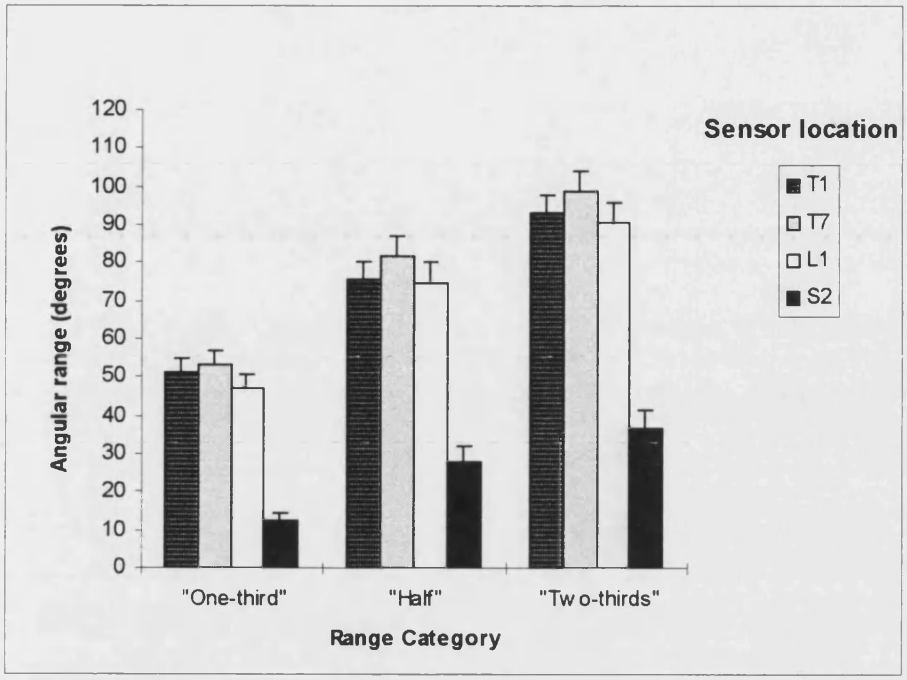


FIG. 8A - Mean angular movement traversed by each sensor in *sagittal flexion* in each of the range categories (standard error bars included)

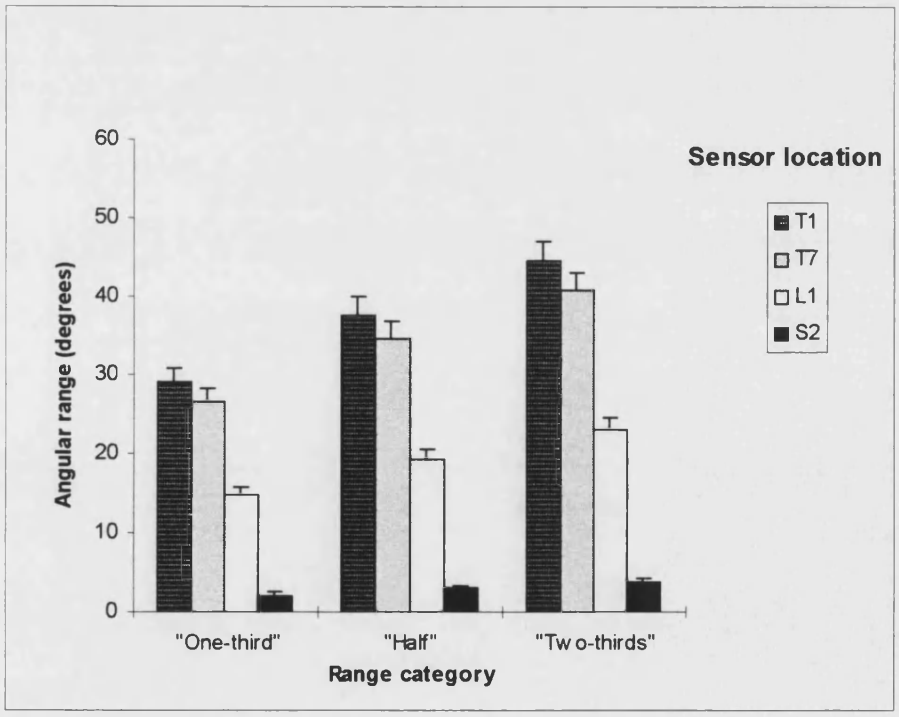


FIG. 8B - Mean angular movement traversed by each sensor in *right coronal flexion* in each of the range categories (standard error bars included)

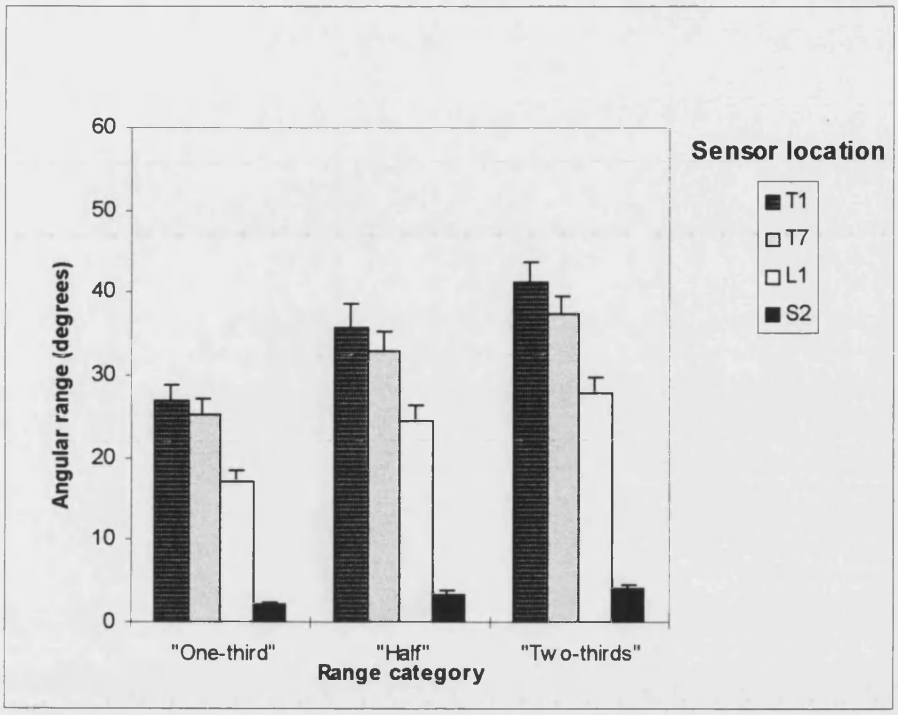


FIG. 8C - Mean angular movement traversed by each sensor in *left coronal flexion* in each of the range categories (standard error bars included)

REGIONAL ANGULAR MOVEMENT (degrees)									
	SAGITTAL FLEXION			RIGHT CORONAL FLEXION			LEFT CORONAL FLEXION		
RANGE CATEGORY>	"1/3"	"1/2"	"2/3"	"1/3"	"1/2"	"2/3"	"1/3"	"1/2"	"2/3"
UPPER THORACIC									
Mean	2.04	6.42	5.75	2.47	3.07	3.92	1.83	2.97	3.83
St. Dev.	6.49	11.05	10.32	2.52	2.76	3.58	2.36	3.46	3.08
LOWER THORACIC									
Mean	6.04	7.16	8.26	2.58	11.75	17.69	7.13	8.36	9.50
St. Dev.	7.48	7.28	6.98	7.94	5.79	4.60	4.86	4.71	5.30
LUMBAR									
Mean	33.25	46.70	53.53	12.58	16.27	18.29	15.76	21.21	23.91
St. Dev.	13.52	11.50	11.06	3.88	4.49	5.09	4.80	5.39	5.56
HIP (S2)									
Mean	12.56	28.03	36.67	2.07	2.94	3.79	2.10	3.37	4.00
St. Dev.	15.45	18.71	19.99	1.51	1.65	2.11	1.45	2.13	2.08

TABLE 17 - Regional angular movement between T1 and T7 (upper thoracic), T7 and L1 (lower thoracic), L1 and S2 (lumbar) and S2 and the vertical (hip)

total and regional angular movement was observed at each sensor location as the requested range increased from "one-third" to "two-thirds." When total angular movements were expressed as a percentage of "full" range, the values at T1 most closely reflected the requested ranges. In sagittal flexion, these were equivalent to 36 ± 8% at "one-third," 52 ± 9% at "half," and 66 ± 9% at "two-thirds" range of movement. In coronal flexion, there was a greater tendency to overestimate the requested range.

4.3.2 Position sense

There were no significant differences in position sense when comparing absolute repositioning error between the three trials carried out within each range category. Undershooting or overshooting of target positions did not show any trial-related trend. Signed error was significantly different in only one instance at T1 on return to upright standing from "one-third" left side flexion. This difference was mainly attributable to four subjects who overshot the first trial compared to the second and third trials. Because differences in error were only significant in this one instance, the mean of the three trials was taken as a measure of position sense within the "one-third," "half" and "two-thirds" range categories. There were no outlying subjects based on the previously stated criteria (p.114).

Measurements of absolute repositioning error are shown in Figures 9A-9C and Table 18 for flexed positions and on return to upright standing in each range category in the sagittal and coronal planes. In nearly all cases, there were no significant differences in repositioning error between each of the three range categories. In the few instances where significant differences were observed (Table 18), post-hoc analysis showed that they occurred between "one-third" and "two-thirds" range categories. The mean differences were small (< 0.8 degrees) in all but one case where a difference of 1.83 degrees was found at S2 between "one-third" and "two-thirds" sagittal flexion. There was no systematic increase or decrease in 95% confidence levels across the three range categories

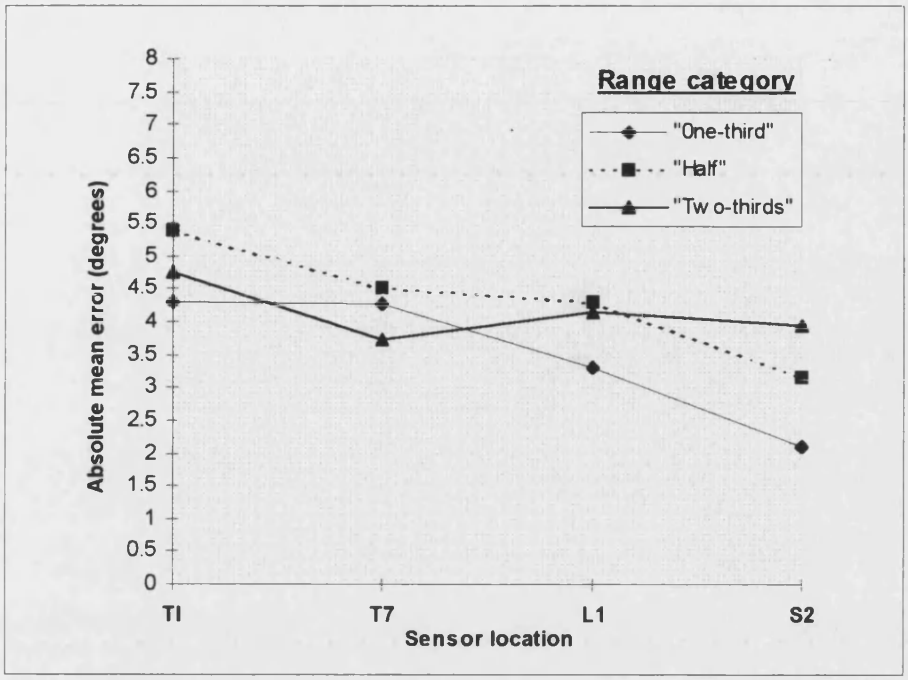


FIG. 9A - Mean absolute repositioning error in *sagittal flexion* in each of the range categories

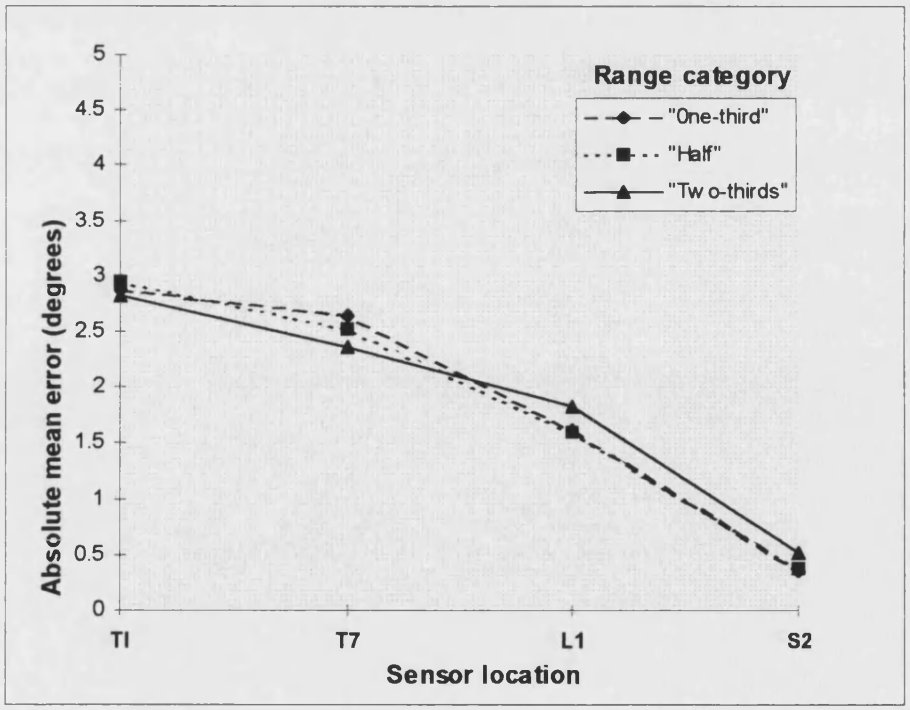


FIG. 9B - Mean absolute repositioning error in *right coronal flexion* in each of the range categories

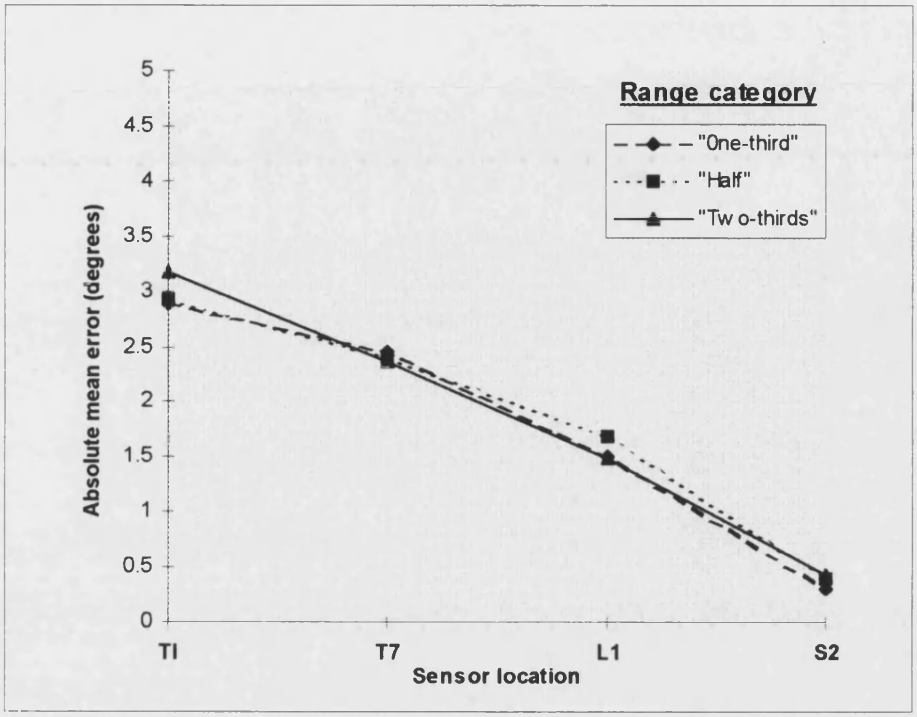


FIG. 9C - Mean absolute repositioning error in *left coronal flexion* in each of the range categories

(1) ABSOLUTE REPOSITIONING ERROR IN UPRIGHT STANDING (deg.)									
	SAGITTAL FLEXION			RIGHT CORONAL FLEXION			LEFT CORONAL FLEXION		
RANGE >	"1/3"	"1/2"	"2/3"	"1/3"	"1/2"	"2/3"	"1/3"	"1/2"	"2/3"
SENSOR LOCATION									
T1									
Mean	2.70	3.11	3.33	1.73	1.87	1.70	1.49	1.61	2.04
St. Dev.	2.20	2.51	2.60	0.83	0.99	0.93	0.81	0.78	0.98
95% CL ±	0.96	1.10	1.14	0.36	0.43	0.41	0.35	0.34	0.43
ANOVA (*p*)		**0.15**			**0.66**			**0.01***	
T7									
Mean	1.94	1.94	2.16	1.48	1.46	1.59	1.46	1.56	1.84
St. Dev.	1.09	1.56	1.21	0.87	0.79	0.87	0.90	1.01	1.15
95% CL ±	0.48	0.68	0.53	0.38	0.35	0.38	0.40	0.44	0.50
ANOVA (*p*)		**0.69**			**0.70**			**0.15**	
L1									
Mean	1.86	2.38	2.59	1.23	1.50	1.46	1.26	1.25	1.45
St. Dev.	1.36	1.40	1.65	0.81	1.07	0.93	0.75	0.60	0.76
95% CL ±	0.59	0.61	0.72	0.36	0.47	0.41	0.33	0.26	0.33
ANOVA (*p*)		**0.03***			**0.12**			**0.42**	
S2									
Mean	1.52	1.29	1.28	0.38	0.37	0.53	0.37	0.36	0.45
St. Dev.	1.07	0.68	0.44	0.35	0.22	0.50	0.22	0.20	0.28
95% CL ±	0.48	0.30	0.19	0.15	0.09	0.22	0.10	0.09	0.12
ANOVA (*p*)		**0.43**			**0.08**			**0.21**	
(2) ABSOLUTE REPOSITIONING ERROR IN FLEXED POSITIONS (deg.)									
	SAGITTAL FLEXION			RIGHT CORONAL FLEXION			LEFT CORONAL FLEXION		
RANGE >	"1/3"	"1/2"	"2/3"	"1/3"	"1/2"	"2/3"	"1/3"	"1/2"	"2/3"
T1									
Mean	4.30	5.38	4.75	2.88	2.94	2.82	2.89	2.92	3.17
St. Dev.	2.84	2.78	2.63	1.31	1.51	1.34	1.67	1.66	1.48
95% CL ±	1.00	1.22	1.15	0.57	0.66	0.59	0.73	0.73	0.65
ANOVA (*p*)		**0.34**			**0.95**			**0.98**	
T7									
Mean	4.27	4.50	3.72	2.65	2.52	2.36	2.46	2.40	2.36
St. Dev.	2.46	2.28	1.85	1.04	1.10	1.13	1.58	1.20	1.43
95% CL ±	1.01	1.00	0.81	0.45	0.48	0.49	0.69	0.53	0.62
ANOVA (*p*)		**0.39**			**0.65**			**0.89**	
L1									
Mean	3.31	4.29	4.15	1.62	1.59	1.83	1.50	1.68	1.48
St. Dev.	1.88	2.29	2.26	0.67	0.75	0.87	0.84	0.71	0.71
95% CL ±	0.82	1.00	0.99	0.30	0.33	0.38	0.37	0.31	0.31
ANOVA (*p*)		**0.22**			**0.47**			**0.55**	
S2									
Mean	2.10	3.17	3.93	0.36	0.37	0.52	0.30	0.40	0.43
St. Dev.	1.06	2.08	2.07	0.19	0.22	0.31	0.15	0.21	0.21
95% CL ±	0.46	0.91	0.91	0.08	0.09	0.14	0.07	0.09	0.09
ANOVA (*p*)		**0.002***			**0.05***			**0.09**	
Results quoted to two decimal places. * denotes statistical significance 95% CL = 95% confidence level about the mean.									

Table 18 - Absolute repositioning error in each of the range categories

The tendency to undershoot or overshoot target positions did not demonstrate any range-related trend but there was a general trend, which reached significance in 38% of trials, for subjects to overshoot flexed positions irrespective of range. Averaging the signed errors of the three trials in each range category reduces the magnitude of repositioning error since overshooting and undershooting errors tend to cancel each other out. Conversely, standard deviations are increased when the direction of error is included in calculations. Signed errors were therefore smaller and standard deviations larger than those for the absolute errors. Signed errors ranged from -1.09 to 1.07 degrees in upright postures and from -2.47 to 3.17 degrees in flexed postures. Differences in signed error between ranges were non-significant in the vast majority of cases (Table 19), although there was a general tendency in flexed postures for signed error to decrease with an increase in range. In two cases, this reached significance: at T7 on right side flexion, and L1 on left side flexion. Significant differences were also observed in two cases on return to upright standing from right and left side flexion at T1. Post-hoc analysis (HSD) showed that in all four cases, the differences were small (0.71-1.33 degrees) and occurred between "one-third" and "two-thirds" range categories.

(1) SIGNED REPOSITIONING ERROR IN UPRIGHT STANDING (degrees)									
	SAGITTAL FLEXION			RIGHT CORONAL FLEXION			LEFT CORONAL FLEXION		
RANGE >	**"1/3"**	**"1/2"**	**"2/3"**	**"1/3"**	**"1/2"**	**"2/3"**	**"1/3"**	**"1/2"**	**"2/3"**
SENSOR LOCATION									
T1									
Mean	-0.38	-0.09	-0.60	0.10	-0.17	-0.77	0.36	0.52	1.07
St. Dev.	12.06	14.51	16.47	1.72	1.95	1.57	1.53	1.61	1.92
95% CL ±	1.52	1.64	1.74	0.76	0.85	0.69	0.67	0.70	0.84
ANOVA (*p*)		**0.31**			**0.02***			**0.03***	
T7									
Mean	1.07	0.87	1.28	0.41	0.29	0.05	-0.11	-0.26	-0.37
St. Dev.	1.55	2.28	1.83	1.47	1.50	1.53	1.64	1.80	2.08
95% CL ±	0.68	0.99	0.80	0.64	0.66	0.67	0.72	0.79	0.91
ANOVA (*p*)		**0.47**			**0.33**			**0.56**	
L1									
Mean	0.75	0.91	1.02	0.47	0.65	0.55	-0.19	-0.18	-0.30
St. Dev.	1.99	2.53	2.61	1.38	1.68	1.44	1.29	1.24	1.56
95% CL ±	0.87	1.11	1.14	0.60	0.73	0.63	0.56	0.54	0.68
ANOVA (*p*)		**0.71**			**0.62**			**0.33**	
S2									
Mean	0.38	0.15	0.36	0.10	0.16	0.18	-0.25	-0.30	-0.19
St. Dev.	1.67	1.31	1.26	0.47	0.61	0.68	0.34	0.25	0.42
95% CL ±	0.73	0.56	0.55	0.21	0.27	0.30	0.15	0.11	0.19
ANOVA (*p*)		**0.61**			**0.52**			**0.22**	
(2) SIGNED REPOSITIONING ERROR IN FLEXED POSITIONS (degrees)									
	SAGITTAL FLEXION			RIGHT CORONAL FLEXION			LEFT CORONAL FLEXION		
RANGE >	**"1/3"**	**"1/2"**	**"2/3"**	**"1/3"**	**"1/2"**	**"2/3"**	**"1/3"**	**"1/2"**	**"2/3"**
T1									
Mean	3.16	2.68	1.72	-2.47	-1.84	-1.41	2.59	2.53	1.79
St. Dev.	3.63	4.44	4.63	1.67	2.56	2.39	1.87	2.15	2.71
95% CL ±	1.59	1.94	2.03	0.73	1.12	1.05	0.82	0.94	1.19
ANOVA (*p*)		**0.44**			**0.10**			**0.49**	
T7									
Mean	2.95	2.11	1.29	-2.22	-1.29	-0.89	2.21	1.93	1.09
St. Dev.	3.10	3.54	3.59	1.49	2.22	2.20	1.68	1.67	2.11
95% CL ±	1.36	1.55	1.57	0.65	0.97	0.96	0.74	0.73	0.92
ANOVA (*p*)		**0.22**			**0.01***			**0.53**	
L1									
Mean	2.41	2.33	1.49	-0.88	-0.49	-0.47	1.12	0.68	0.29
St. Dev.	2.65	3.41	4.27	1.43	1.62	1.71	1.22	1.40	1.25
95% CL ±	1.16	1.49	1.87	0.63	0.71	0.75	0.54	0.61	0.55
ANOVA (*p*)		**0.53**			**0.41**			**0.02***	
S2									
Mean	1.28	0.39	0.48	-0.15	-0.14	-0.26	0.07	0.05	-0.04
St. Dev.	1.57	3.27	3.94	0.28	0.36	0.42	0.28	0.31	0.39
95% CL ±	0.69	1.43	1.72	0.12	0.16	0.18	0.12	0.14	0.17
ANOVA (*p*)		**0.44**			**0.41**			**0.43**	
Results quoted to two decimal places. * denotes statistical significance 95% CL = 95% confidence level about the mean.									

TABLE 19 - Signed (+/-) repositioning error in each of the range categories

4.4 DISCUSSION

The results of this study indicate that subjects were able to discriminate between incremental ranges of movement, though total and regional ranges of movement varied greatly between individuals. Subjects appeared to gauge movements in the sagittal plane by head position since measures taken at T1 most accurately represented criterion ranges of movement. There was little regional movement on sagittal flexion in the thoracic spine with some subjects even extending slightly on forward bending. Most sagittal flexion occurred in the hip and lumbar regions. In the coronal plane, side-flexion occurred predominantly in the lower thoracic and lumbar regions. These findings are representative of normal regional physiological movement in the sagittal and coronal planes (White et. al. 1990).

Spinal position sense was found to be little affected by range of movement. In approximately one-third of the tests there was a slight trend towards diminished position sense with increasing range of movement but this reached significance in only four instances. With the exception of forward flexion at the sacrum, these differences accounted for less than 2.5% of the total angular range moved so they are unlikely to be of functional significance.

Sagittal flexion of the sacrum at S2 corresponds to straight-legged hip flexion, and here a significant decrease in position sense accuity between "one-third" and "two-thirds" of the range was found. This is associated with an almost double increase in the 95% confidence level of measurements between these range categories. No other studies appear to have assessed active absolute position sense of the hip over different ranges of movement, although one study did assess signed errors. This earlier study found a decrease in signed error with increasing range of hip flexion (Stender and Drowatzky 1994). This was also observed in the present study where signed error was greater at "one-third" compared to "two-thirds" range of hip flexion.

The position sense results obtained in this study are similar to those reported in the previous reliability study (Chapter 3) using the same technique, and to those of earlier studies which assessed spinal position sense in response to large displacements (Revel et. al. 1991, 1994, Maffey-Ward et. al. 1996, Loudon et. al. 1997). Maffey-Ward, (1996) for example, reported mean sagittal lumbo-pelvic position sense of 2.6 degrees and Revel et. al. (1991,1994) sagittal cervical position sense of 3.37 degrees on return to neutral, upright positions. These findings correspond to our mean findings of 2.28 degrees at L1 and 3.05 degrees at T1 in upright positions following sagittal flexion. However, other workers have reported smaller repositioning errors in response to smaller movements (Jakobs et. al. 1985, Ashton-Miller 1992, Parkhurst and Burnett 1994). Parkhurst and Burnett (1994) assessed repositioning accuracy in the lower back at positions "approximately 5 degrees" from a neutral starting position. They reported mean repositioning accuracy of 23.3 mm (1.17 degrees) in the sagittal plane and 16.5 mm (0.83 degrees) in the coronal plane. These results reflect our findings of superior coronal position sense but are lower than our mean repositioning errors at L1. These differences may be due to metholodological variations between the studies since this earlier study assessed position sense in lying rather than free-standing postures. This may have led to an increase in exteroceptive cues, which, under some circumstances have been shown to improve position sense accuity (Perlau et. al. 1995, Heit et. al. 1996).

The results of this study support previous findings in the reliability study (Chapter 3) that position sense is better in upright than non-upright positions indicating a possible influence of the vestibular apparatus. Motor behaviour experiments which incorporate variations in target distance sometimes report a response bias in location reproduction tasks with subjects tending to either overestimate or underestimate larger movements (Poulton 1979, Walsh and Russell 1980, Wrisberg and Winter 1985, Immanaka et. al. 1989, Abrams et. al. 1990, Jerosch and Prymka 1996). This study, however, suggests that qualitative aspects of proprioception are not significantly range-dependent. The biases reported by previous workers are usually a response to shifts in starting position (Walsh and Russell 1980,

Wrisberg and Winter 1985, Immanaka 1989, Jaric et. al. 1992) and these motor behaviour studies have all been conducted on the upper limb. In this current study there was no particular bias towards undershooting or overshooting on return to upright postures regardless of the starting position ie. "one-third," "half" or "two-thirds" of the range, and this may again reflect input from the vestibular apparatus. In coronal and sagittal flexion, where there was little variation in the upright starting position, however, there was a bias towards overestimating target positions regardless of range. A similar overshooting bias has been reported in the healthy loaded spine in sagittal flexion (Field et. al. 1991) suggesting that it may reflect spinal proprioception under conditions of increased gravitational loading.

Both regional and total spinal movements are likely to make an important contribution to overall spinal position sense. Regional movement of one vertebra relative to another will produce the most strain in small intersegmental muscles and ligaments which are richly endowed with muscle spindles (Nitz and Peck 1986). Correspondingly, larger movements of the whole spine will produce strain in polysegmental tissues such as the thoracolumbar fascia and erector spinae muscles, which may therefore contribute more to position sense towards the extremes of the range of movement. The interplay between these various proprioceptive outputs probably explains how proprioceptive acuity is maintained throughout the full range of movement.

4.5 SUMMARY

Spinal position sense was little affected by range of movement. Where significant differences existed they represented less than 2.5 % of the total angular range. Hip position sense was subject to range effects where there were large variations in movement. Movement of T1 most closely represented subjects perception of the total range of sagittal flexion. This may be a reflection of head position sense. Adoption of precise criterion positions, which is difficult to achieve experimentally, may not be an essential pre-requisite of spinal position sense protocols. This study showed that simultaneous regional assessment of spinal position sense under natural, self-paced conditions, is little affected by total or regional variations in angular range.

CHAPTER 5

SPINAL POSITION SENSE IN PATIENTS WITH ANKYLOSING SPONDYLITIS AND HEALTHY CONTROLS - A COMPARATIVE STUDY

5.1 INTRODUCTION

Previous chapters detailed the development of a new technique for measuring regional spinal position sense (Chapter 2), and described further studies which assessed both the reliability of the technique (Chapter 3) and the effect of magnitude of movement on position sense (Chapter 4). This chapter describes a study in which the newly developed and validated technique was used to investigate the hypothesis that pathological processes in AS, particularly entheseopathy (pp. 47-49), cause deficits in spinal position sense in patients with ankylosing spondylitis.

Empirical evidence of impaired proprioception in spinal pathology appears to be supported by the findings of two recent studies. In a study of spinal position sense in twenty healthy volunteers, Gill and Callaghan (1998) found that these subjects were, on average, 2.3 degrees more accurate in actively repositioning the spine compared with patients with chronic low back pain. Although this study reports statistical significance, the clinical implications of this deficit were not explored, for example, by examination of the association between position sense findings and proprioceptive dependent outcomes such as function. Parkhurst and Burnett (1994), however, do explore the association between the results of lumbar proprioception tests on 88 male firefighters (aged 21-56 years), anthropometric and other data. Correlation coefficients between test results and other variables are low ($r < 0.35$) but weak significant associations are reported between diminished proprioceptive acuity, age and a history of low back injury. Several studies have been carried out on active position sense in patients with cervical disorders. Revel et. al. (1991) report that patients (aged 25-73 years) with cervical pain are on average 2.4 degrees less accurate in active midline position sense compared with healthy controls. In a further study they examine the effects of a proprioceptive rehabilitation programme on position sense in neck pain patients. Although pre- and post-rehabilitation data include functional and other outcome measures, the association between these and position sense results is not explored (Revel et. al. 1994). Whiplash injuries of the neck, which may

involve widespread damage to proprioceptive structures, have also been shown to cause qualitative and quantitative deficits in midline position sense (Loudon et. al. 1997).

The results of these studies of spinal proprioception and pathology suggest an association between the two. Results tend to reinforce the popular concept that direct damage to proprioceptive afferents causes measurable and clinically significant impairment in proprioception. These studies are, however, based on subjects with general localised conditions such as chronic low back or neck pain rather than specific pathologies. In addition, the association between spinal proprioception and other endpoints remains largely unexplored. More substantive evidence on the effect of spinal pathology on proprioception could be obtained by investigation of a relatively homogenous group of subjects with anatomically specific spinal pathology and clinical features which may be attributable to proprioceptive change. Ankylosing spondylitis, with its pathological specificity for important sites of proprioceptive afferents and a classic clinical feature of postural deformity, provides one such opportunity. Multidimensional endpoint measures specifically designed for this patient group have also recently been validated so that relationships between these and spinal position sense may be explored.

The main aim of this study is to investigate the hypothesis that spinal pathology in AS impairs spinal position sense in patients with mild disease (pp. 84-85). Spinal position sense in these patients will be compared with normative data obtained from healthy controls. In addition, this hypothesis will also be investigated by exploring the association between spinal position sense and disease progression endpoint measures in AS patients (pp. 40-41, 85).

5.2 METHODS

5.2.1 Subjects

5.2.1.1 Healthy controls

Fifty healthy volunteers (27 male:23 female, mean age 31.42 years) gave informed consent to take part in this study. An information sheet outlining the requirements of the study (Appendix 2) was given to subjects prior to obtaining their consent. Volunteers were recruited from local hospital and university departments, held a wide variety of sedentary

and manual posts, and included porters, caterers, laboratory technicians and post-graduate students. Subjects were screened by medical questionnaire to ensure that they did not meet any of the exclusion criteria of the study. People with a history of trauma, surgery or disease of the spine or lower limbs, diabetes or neurologic disorders were excluded because these conditions may effect proprioceptive ability. Similarly, volunteers who had problems with balance, hearing or vision (not corrected by glasses) were excluded. Pregnant women or those with a recent history of pregnancy (within six months) were also omitted from the trial. Five of the original volunteers were excluded on the basis of these criteria. They had histories of a fractured femur, ankle/knee ligament injury, back surgery and Meniere's disease. Table 20 gives the physical characteristics of the controls who took part in the study.

	CONTROLS	AS PATIENTS
Age: Mean	31.4	34.8
(years) Range	19-52	21-50
Height: Mean	1.72	1.74
(m.) Range	1.55-1.98	1.55-1.94
Weight: Mean	68.50	74.25
(kgs.) Range	51.71-100.00	51.25-109.20
Male/Female	27/23	35/15
Right/left handed	44/6	48/2

TABLE 20 - Physical characteristics of subjects in the comparative study

5.2.1.2 AS patients

Fifty ankylosing spondylitis patients (Table 20) were recruited from both in-patients and out-patients of the Royal National Hospital for Rheumatic Diseases (RNHRD), Bath. All patients had been diagnosed by consultant rheumatologists. Diagnosis of AS was on the basis of the modified New York criteria (van der Linden 1984) and patients had both clinical and radiographic signs of disease. Exclusion criteria were identical to those of controls with the addition of the following:

- total hip replacement
- not currently receiving formal physiotherapy treatment for AS or any other condition
- achilles tendonitis, plantar fasciitis or bursitis
- a "flare-up" of AS in peripheral or axial joints
- sciatica
- participation in other research trials

The inclusion criterion was a score of 3 or less on all five components of the Bath Ankylosing Spondylitis Metrology Index (BASMI) (Appendix 1). Table 21 shows the ranges of movement required within each component of the BASMI to meet this criterion. This criterion was adopted because pilot studies (Chapter 2) had shown that the more general criterion of an average BASMI of 3 ("Fast" group patients) could mask patients with moderate or severe limitation of movement in one or two BASMI components. To assess the reliability of the technique in patients, eighteen were retested, at the same time of day, after an interval of two weeks during which they did not receive any formal physiotherapy treatment (see Chapter 3 for the reliability of the technique in controls).

Six of the patients who voluntered were excluded on the basis of the entry criteria. Two of these had a score greater than 3 in one component of the metrology index (BASMI), one had plantar fasciitis, one had a previous knee injury, one had recently been pregnant and one was experiencing a flare-up of AS. Twelve patients were not on medication. The remaining thirty-eight were receiving non-steroidal anti-inflammatory drugs such as Ibuprofen and Naproxen.

BASMI	NAME OF TEST	BASMI 3 OR LESS
1	TRAGUS TO WALL (cm)	< 18
2	LUMBAR FLEXION (cm)	> 5
3	INTERMALLEOLAR (cm)	> 90
4	CERVICAL ROTATION (degrees)	> 59.6
5	LUMBAR SIDE FLEXION (cm)	> 15.9

TABLE 21 - Minimum criteria for a Bath Ankylosing Spondylitis Metrology Index (BASMI) of 3 or less

In-patients were recruited from patients about to commence a "fast" two-week rehabilitation programme at the RNHRD. "Fast" in-patient courses are normally run five times a year. In the last year of data collection, the general increase in demand for in-patient rehabilitation, meant that some "fast" patients attended "fast/moderate" groups. Physiotherapy records, including BASMI ratings, of attendees were examined in advance to ascertain those most likely to meet the study criteria. BASMI ratings on AS patients attending follow-up out-patient appointments are routinely taken by specialist physiotherapists and recorded in physiotherapy records. The requirements of the study

were explained to those patients likely to meet study criteria and they were given an information sheet (Appendix 2). Patients were recruited from "fast" groups (and latterly from "fast-moderate" groups) over a period of three years. Between 10-60% of patients in these groups fulfilled the study criteria and, with one exception, all volunteered to take part in the study. One patient declined because he felt participation in the study might be detrimental to his performance on the course. A total of 26 in-patients were admitted to the trial. Position sense testing was carried out prior to commencement of the in-patient rehabilitation programme.

Out-patients were attendees of clinics at the RNHRD (24 patients). Potential study participants were identified from the physiotherapy records and BASMI ratings of patients who had been measured in the last six months. They were contacted in person during routine out-patient physiotherapy measurement sessions (7), local National Ankylosing Spondylitis Society (NASS) group meetings (3) or by post (14). Patients contacted by post were sent an information sheet (Appendix 2) and a reply slip to indicate their willingness to be contacted by telephone to discuss the study. The requirements of the study were explained to those patients likely to meet study criteria. With three exceptions, all out-patients who met the study criteria agreed to take part in the study. Two out-patients did not respond to the postal enquiry; one of these subsequently agreed to take part in the study as an in-patient. One out-patient declined to take part because he did not like standing still. Testing for out-patients was carried out during attendance at routine out-patients appointments or at another convenient time.

5.2.3 Experimental protocol

Metrological scoring (BASMI) of patients who agreed to take part in the study was undertaken by one of three physiotherapists specialising in AS. Patients with a BASMI of 3 or less were given an administered medical questionnaire (Appendix 2) to ascertain whether they fulfilled any of the exclusion criteria of the study. Patients subsequently accepted into the study were asked to complete self-administered questionnaires for the Bath AS Functional Index (BASFI), Bath AS Disease Activity Index (BASDAI), and Bath AS Global Index (BASG-1) (Appendix 1). For ethical reasons, the Bath AS Radiographic Index (BASRI) was only obtained for patients with pre-existing radiographs. A record was

made of self-assessed years since diagnosis and years since start of the disease. Healthy controls and patients were measured at least 3 hours after rising to eliminate any diurnal effects on spinal mobility. Records were made of age, height, weight and hand dominance. Ethical permission for this study was obtained from the Wiltshire and Bath Health Authority.

The procedure for determining position sense was as described in the reliability study in Chapter 3. The four Fastrak sensors were attached at T1, T7, L1 and S2 in the manner previously described (pp.89-90). The position of the Fastrak source on the wooden stand was adjusted for each subject so that the optimal testing range of 20-81 cm was maintained throughout the experimental procedure. Subjects wore loose fitting shorts and adopted a stance that felt safe and balanced for all test movements. A note was made of the position of the source and the distance between heels and big toes for use in subsequent testing sessions. All metal was removed from the immediate operating environment of the Fastrak, with the occasional exception of wedding rings and belly studs. A full verbal explanation of the procedure was given at the start of the experiment. Care was taken to ensure that expectations of "halfway" positions were not conveyed by the body language of the operator.

At the start of the experiment subjects were required to stand with arms folded and knees straight and to complete one randomised movement in each of the following directions; forward flexion, and left and right side flexion "as far as you comfortably can." It was explained to subjects that this was intended to help gauge subsequent "halfway" flexed positions. This, and the instruction to move "as far as you comfortably can," was also intended to ensure that AS patients, familiar with BASMI measurement procedures, did not provoke pain by forceful movements to the end of range. Position sense was determined by assessing subjects ability to reproduce flexed and upright positions of the spine in the sagittal and coronal plane while blindfolded to remove visual input. The blindfold was removed in the short period between each test. Patients were instructed to report any discomfort and, if this happened, they were asked to grade the discomfort on a scale of 0-10. A total of nine randomised tests were performed in flexed and upright positions in the sagittal and coronal plane.

The error in reproducing positions in flexed "halfway" and upright positions was derived from analysis of movement graphs for each test (Fig 4. p.100). Data from these graphs were collated onto computer spreadsheets using Excel softwear. Repositioning error was recorded as the absolute error between angular measurements taken in each postion. The direction of error in each individual test at each sensor location was also recorded ("signed" error) to determine the number of tests in which subjects over-or under-estimated the target position. Regional angular range of movement in the thoracic and lumbar spine and the total angular range of movement traversed by each sensor into flexed positions was determined as previously described (p.131). Data was stored on a computer disc and statistical analysis was conducted retrospectively at the end of the trial.

5.2.4 Statistical Analysis

Within-day reliability of position sense measurements in patients was analysed using a single factor repeated measures analysis of variance (ANOVA). Day-to-day day variation was assessed using a nested ANOVA, treating subjects as a fixed effect at the top level with sessions nested within subjects. In both cases, the association between repeated measurements was assessed using the intraclass correlation coefficient (ICC). The precision and 95% confidence limits of measurements were also assessed using the standard error of measurement (SEM, Appendix 3).

The mean of the three trials in each position has previously been shown to provide the most reliable measure of position sense (Chapter 3). Position sense in AS patients and healthy controls was, therefore, compared by unrelated two-sample t-tests on mean results for each position. This test was also used to compare the angular range of movement at each sensor, and the regional range of movement in the upper and lower thoracic and lumbar spine, in "half-way" positions in patients and controls. Differences in overshooting or undershooting of target positions within subject groups were investigated using the binomial test to assess whether results were due to random error. These differences were also assessed using the chi-squared test (χ^2). Scatter plots and the Pearson product moment correlation coefficient (r) were used to examine the association between position sense and other endpoint measures in AS. Statistical tests were two-tailed and a significance level of

5% was adopted. Details of the less well-known statistical tests used in this study are contained in Appendix 3.

The sample size of 50 subjects in each group was determined from a table of power statistics for the t-test (Hulley and Cummings 1988). With a two-tailed α of 0.05 and β level of 0.20 (a power of 80%), a sample size of 50 gives a standardised effect size of 0.52. The standardised effect size is the expected effect size divided by the standard deviation of the outcome variable. The largest standard deviation in the data from the reliability study on controls (Chapter 3) is 4.92 degrees (L1, sagittal flexion) and a standardised effect size of 0.52 based on this data would give an expected effect size of 2.6 at L1 in positions in sagittal flexion. This effect size is similar to the size of deficit in spinal proprioception reported in studies involving patients with pathology (p.36). The effect size is determined from the size of the smallest effect that would be clinically meaningful. However, the size of this effect in position sense tests is unknown (p.40-41). In the absence of this information, a mean difference of 50% in position sense measurements at L1, the sensor with the largest standard deviation, would be detected by a sample size of 50. This appears to an adequate sample size in the absence of any substantive evidence on the magnitude of difference required for clinical relevance.

5.3 RESULTS

5.3.1 Reliability of position sense measurements in AS patients

There were no significant within-day differences in repositioning error between the three trials in AS patients (Table 22). Day-to-day, there was one significant difference at T7 in upright standing on return from right side flexion (Table 23). Intra-class correlation coefficients between mean day 1 and day 2 measurements (Table 24) showed good correlation at L1 and S2 in upright standing on return from sagittal flexion. For "halfway" positions in this plane, however, coefficients were low ranging from *R* -0.27 to *R* 0.54. In the coronal plane, intra-class correlation coefficients at S2 were variable ranging from *R* 0.43 to 0.89. Correlation at other sites on return to upright standing from the right or left was, however, good, ranging from *R* 0.65 to *R* 0.86. "Halfway" positions in left side flexion at sites other than S2 also demonstrated good intra-class correlation ranging from *R*

0.60 at L1 to *R* 0.87 at T7. The standard error of measurement (SEM, Appendix 3) at each of the sensors and in all of the different positions ranged from 0.10 to 1.58 degrees (Table 25). Repeated measurements at T1 in the sagittal plane had the widest 95% confidence limits (these are ± 2 x SEM) and those at S2 positions in the coronal plane the narrowest. There were no outlying subjects based on the previously stated criteria (p.117).

	LOCATION OF SENSOR											
	T1			T7			L1			S2		
Test No. >	1	2	3	1	2	3	1	2	3	1	2	3
SAGITTAL FLEXION												
"HALFWAY"												
Mean	4.38	3.65	3.48	3.65	3.36	3.25	3.57	3.51	3.12	2.32	3.42	2.88
St. Dev.	2.97	2.83	4.31	3.33	2.34	2.74	2.34	2.44	3.16	1.63	1.85	3.20
ANOVA (p)	**0.70**			**0.90**			**0.86**			**0.38**		
UPRIGHT ST												
Mean	2.83	2.77	2.77	1.55	1.67	1.39	1.56	1.80	1.78	1.89	2.33	1.72
St. Dev.	2.54	2.11	1.82	1.09	1.65	0.72	1.45	2.10	1.68	1.43	2.29	1.40
ANOVA (p)	**0.98**			**0.78**			**0.90**			**0.56**		
R. CORONAL FLEXION												
"HALFWAY"												
Mean	2.27	2.73	2.31	1.90	2.17	2.18	1.12	1.21	1.16	0.34	0.34	0.37
St. Dev.	2.18	2.41	1.83	1.21	2.12	1.84	0.97	1.14	1.19	0.28	0.30	0.36
ANOVA (p)	**0.78**			**0.87**			**0.97**			**0.96**		
UPRIGHT ST												
Mean	2.04	1.97	1.80	1.52	1.84	1.99	1.18	1.14	1.31	0.31	0.74	0.45
St. Dev.	2.47	1.42	1.37	1.38	1.18	2.73	1.21	0.86	1.22	0.25	1.71	0.51
ANOVA (p)	0.92			0.75			0.90			0.44		
L. CORONAL FLEXION												
"HALFWAY"												
Mean	3.61	3.30	2.98	2.36	2.17	2.46	1.61	1.81	1.72	0.43	0.47	0.46
St. Dev.	2.51	2.66	2.16	1.62	1.82	1.68	0.89	1.84	1.10	0.58	0.35	0.47
ANOVA (p)	**0.75**			**0.88**			**0.91**			**0.97**		
UPRIGHT ST												
Mean	2.01	1.90	2.06	1.91	1.75	2.09	1.27	1.19	1.41	0.44	0.53	0.48
St. Dev.	2.08	1.12	1.74	1.42	1.13	1.58	1.10	0.80	1.14	0.39	0.52	0.42
ANOVA (p)	**0.96**			**0.77**			**0.81**			**0.83**		
Results are the absolute repositioning errors in degrees quoted to two decimal places												

TABLE 22 - Within-day reliability of spinal position sense measurements in AS patients

	UPRIGHT STANDING POSITIONS						"HALFWAY" POSITIONS					
Location of Sensor	**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**		**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**	
	Day 1	**Day 2**	**Day 1**	**Day 2**	**Day 1**	**Day 2**	**Day 1**	**Day 2**	**Day 1**	**Day 2**	**Day 1**	**Day 2**
T1 Mean	2.77	1.90	2.01	1.75	1.99	1.62	3.84	3.39	2.5	2.29	3.30	3.15
St. Dev	1.36	1.21	1.84	1.22	1.25	1.15	1.90	1.83	1.98	1.14	2.12	2.27
ANOVA (p)	**0.07**		**0.71**		**0.12**		**0.29**		**0.06**		**0.20**	
T7 Mean	1.54	1.94	1.68	1.36	1.92	1.51	3.42	3.12	2.04	2.00	2.31	2.70
St. Dev	0.73	1.04	1.20	1.00	1.09	0.88	1.25	1.72	1.16	0.81	1.40	1.78
ANOVA (p)	**0.09**		**0.02***		**0.10**		**0.65**		**0.30**		**0.99**	
L1 Mean	1.71	2.11	1.16	1.20	1.29	1.23	3.40	3.48	1.16	1.07	1.71	1.72
St. Dev	1.52	1.83	0.84	0.92	0.76	0.90	1.12	1.75	0.83	0.47	1.02	1.00
ANOVA (p)	**0.31**		**0.38**		**0.10**		**0.90**		**0.06**		**0.40**	
S2 Mean	1.98	1.90	0.53	0.36	0.49	0.44	2.87	2.22	0.53	0.42	0.45	0.40
St. Dev	1.45	1.13	0.88	0.19	0.32	0.30	1.38	1.06	0.88	0.41	0.27	0.28
ANOVA (p)	**0.62**		**0.33**		**0.88**		**0.55**		**0.45**		**0.06**	

* denotes statistical significance. Results are the absolute repositioning errors in degrees quoted to two decimal places. Standard deviations are derived from the individual results of each subject for all three tests carried out on each day.

TABLE 23 - Day-to-day reliability of position sense measurements in AS patients

	SAGITTAL FLEXION		R. CORONAL FLEXION		L. CORONAL FLEXION	
Sensor location	**Upright st.**	**"Halfway"**	**Upright st.**	**"Halfway"**	**Upright st.**	**"Halfway"**
T1						
Day 1	0.289	-0.091	0.813	0.825	0.602	0.836
Day 1-2	-0.129	-0.266	0.859	0.623	0.647	0.748
T7						
Day 1	0.171	-0.963	0.834	0.488	0.704	0.761
Day 1-2	-0.339	0.238	0.773	0.388	0.770	0.872
L1						
Day 1	0.836	-1.253	0.726	0.724	0.611	0.657
Day 1-2	0.918	0.544	0.738	0.057	0.709	0.602
S2						
Day 1	0.763	0.071	0.382	0.534	0.557	0.008
Day 1-2	0.844	0.324	0.429	0.491	0.889	-0.433

TABLE 24 - Within-day and day-to-day (average of three tests in each position) intraclass correlation coefficients (*R*) of spinal position sense measurements in AS patients

	FORWARD FLEXION		RIGHT SIDE FLEXION		LEFT SIDE FLEXION	
Site of sensor	**Upright Standing**	**"Halfway"**	**Upright Standing**	**"Halfway"**	**Upright Standing**	**"Halfway"**
T1	1.23	1.58	0.59	0.98	0.70	1.08
T7	0.74	1.30	0.52	0.77	0.47	0.56
L1	0.48	0.98	0.45	0.64	0.44	0.63
S2	0.50	1.02	0.48	0.24	0.10	0.20
* Results (in degrees) are quoted to two decimal places						

TABLE 25 - Standard error of measurement (SEM) at each of the sensor sites and in each of the test positions in AS patients

5.3.2 Comparison of patients and controls

5.3.2.1 Absolute repositioning error

Results showed that in most cases there were no significant differences in spinal position sense between ankylosing spondylitis patients and controls (Table 26). There was, however, a trend for greater position sense accuracy in AS patients at all sensor sites and in all positions compared with controls (Figs.10A-10C, 11A-11C). This trend reached

significance in upright standing at L1 on return from right coronal flexion (p 0.017, Fig. 10B). For "halfway" positions, significance was reached at T7 (p 0.005) and S2 (p 0.004) on "halfway" left side flexion (Fig. 11C). "Halfway" sagittal flexion at T1 was just significant at p 0.05 (Fig. 11A). Mean significant differences were small, ranging from 0.19 degrees at S2 to 1.02 degrees at T1.

	UPRIGHT STANDING POSITIONS						"HALFWAY" POSITIONS					
Location of Sensor	**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**		**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**	
	CT	**AS**	**CT**	**AS**	**CT**	**AS**	**CT**	**AS**	**CT**	**AS**	**CT**	**AS**
T1												
Mean	3.42	2.76	1.89	1.95	1.94	1.83	4.86	3.88	2.93	2.61	3.10	2.53
St. Dev.	2.34	1.82	1.14	0.97	0.91	0.96	2.81	2.10	1.65	1.53	1.53	1.40
95% C.L.	0.64	0.50	0.32	0.33	0.25	0.26	0.78	0.78	0.46	0.42	0.42	0.41
t-test (p)	**0.12**		**0.82**		**0.56**		**0.05***		**0.32**		**0.06**	
T7												
Mean	2.36	1.97	1.80	1.51	1.77	1.83	4.37	3.53	2.54	2.20	2.56	1.88
St. Dev	1.51	1.09	1.04	0.67	1.01	1.15	2.56	1.72	1.35	1.13	1.29	1.00
95% C.L.	0.42	0.30	0.29	0.18	0.28	0.31	0.71	0.48	0.38	0.31	0.36	0.30
ANOVA (p)	**0.14**		**0.10**		**0.31**		**0.06**		**0.17**		**0.005***	
L1												
Mean	2.24	1.86	1.47	1.04	1.16	1.02	4.23	3.57	1.62	1.40	1.84	1.49
St. Dev	1.35	1.37	1.01	0.71	0.63	0.69	2.74	1.62	0.76	0.80	1.08	0.80
95% C.L.	0.37	0.37	0.28	0.20	0.17	0.19	0.76	0.45	0.21	0.24	0.36	0.30
ANOVA (p)	**0.17**		**0.017***		**0.31**		**0.15**		**0.19**		**0.06**	
S2												
Mean	1.51	1.51	0.43	0.34	0.41	0.44	2.62	2.63	0.45	0.46	0.58	0.39
St. Dev	0.89	0.99	0.32	0.21	0.23	0.30	1.22	1.60	0.34	0.30	0.40	0.24
95% C.L.	0.25	0.27	0.09	0.06	0.06	0.07	0.45	0.34	0.09	0.09	0.12	0.07
ANOVA (p)	**0.99**		**0.12**		**0.78**		**0.96**		**0.89**		**0.004***	

* Denotes statistical significance. Results are the absolute repositioning errors in degrees quoted to two decimal places. Standard deviations are derived from the individual results of each subject for all three tests carried out on each day. 95% confidence levels (95% C.L.) are based on the averaged results of each subject. CT=Controls, AS=Ankylosing spondylitis patients

TABLE 26 - Position sense in upright standing and flexed positions Comparison of patients and controls

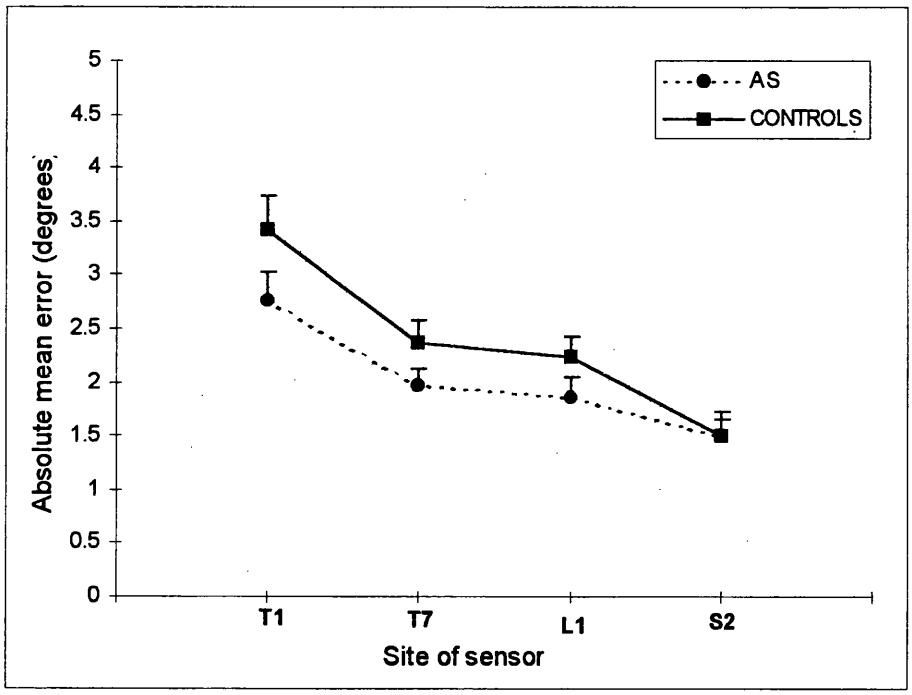


FIG. 10A - Mean repositioning error on return to upright standing from *sagittal flexion* in AS patients and healthy controls. Standard error bars included.

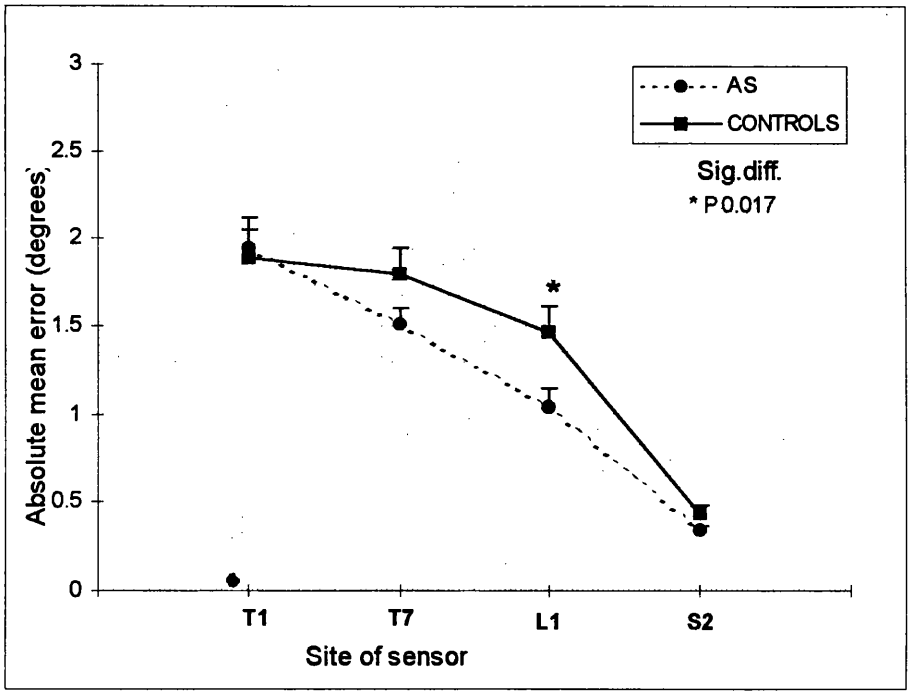


FIG. 10B - Mean repositioning error on return to upright standing from *right coronal flexion* in AS patients and healthy controls. Standard error bars included. Asterisk * denotes statistically significant difference between AS patients and controls.

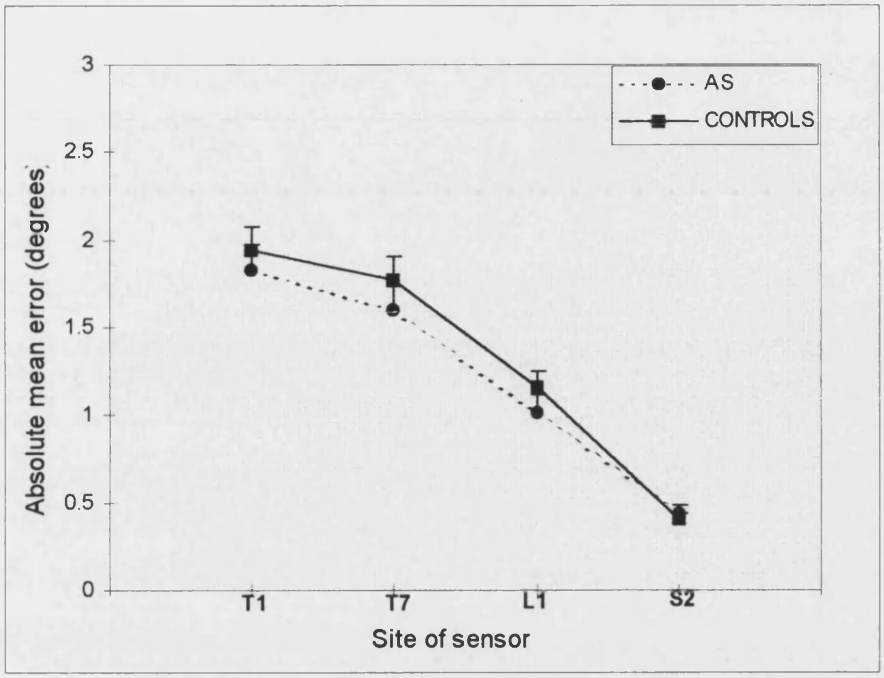


FIG. 10C - Mean repositioning error on return to upright standing from *right coronal flexion* in AS patients and healthy controls. Standard error bars included.

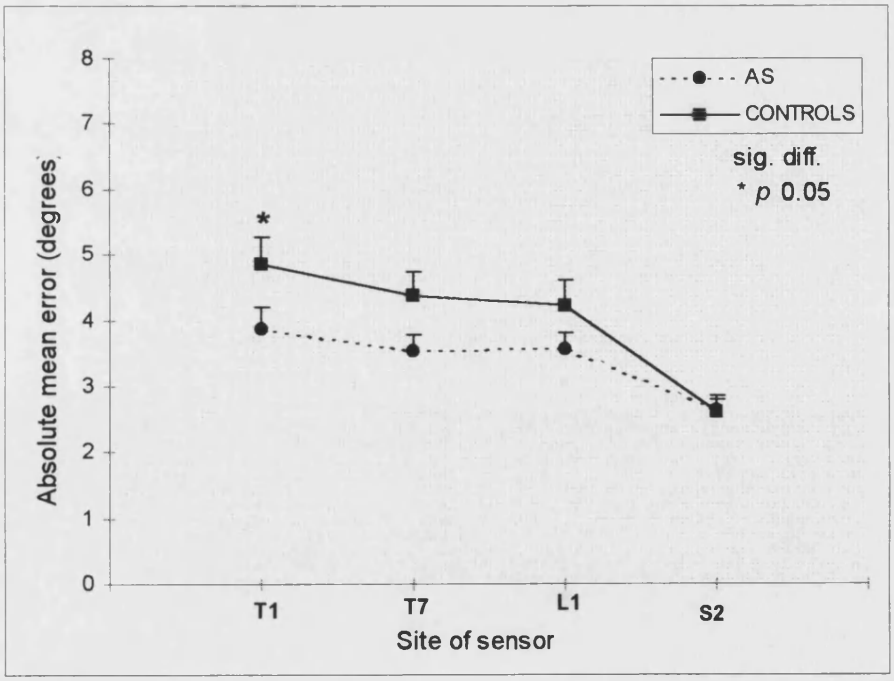


FIG. 11A - Mean repositioning error in "halfway" positions in the *sagittal plane* in AS patients and healthy controls. Standard error bars included. Asterisk * denotes statistically significant difference between AS patients and controls.

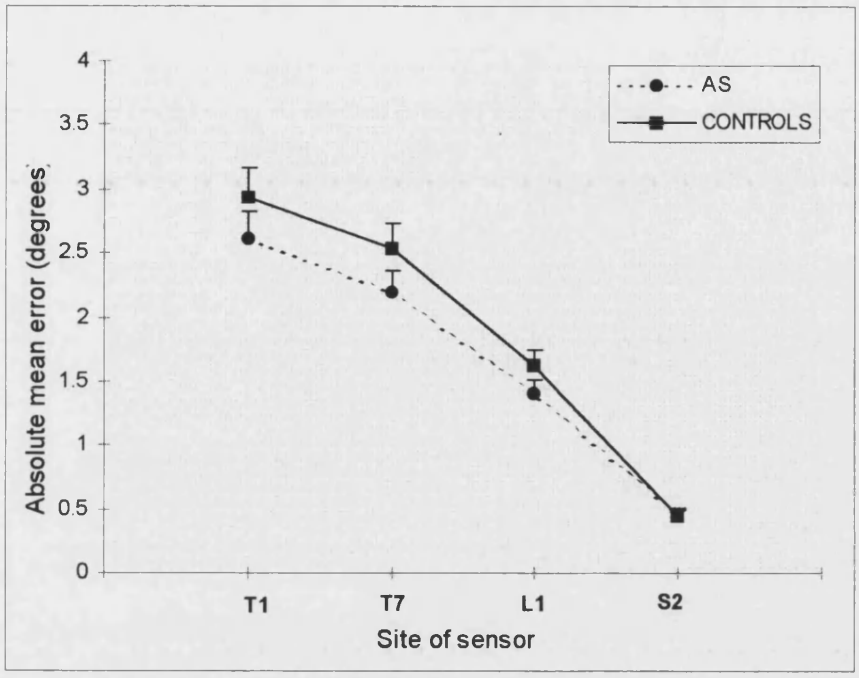


FIG. 11B - Mean repositioning error in "halfway" positions in the *right coronal plane* in AS patients and healthy controls. Standard error bars included.

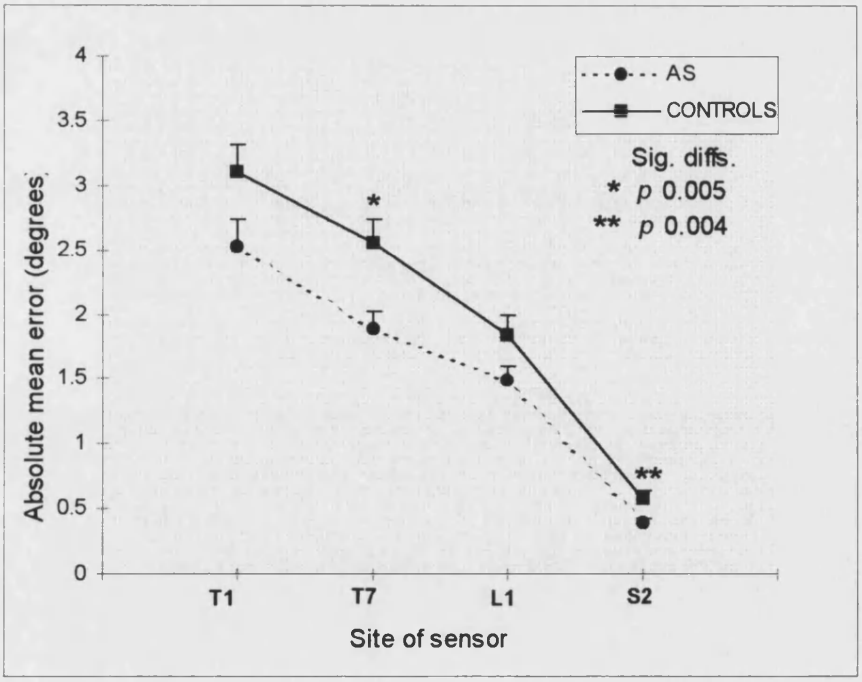


FIG. 11C - Mean repositioning error in "halfway" positions in the *left coronal plane* in AS patients and healthy controls. Standard error bars included. Asterisks * and ** denote statistically significant differences between AS patients and controls

There were no outlying subjects based on the previously stated criteria (p.114).

The trend towards greater accuracy in AS patients was examined by subdividing them into a recent (5 years or less) diagnostic group (26 patients, mean age 31 years) and later (more than 5 years) diagnostic group (24 patients, mean age 37 years). Results are shown in Table 27 and Figures 12A-12C and 13A-13C. As with the whole patient group, there is a trend, which sometimes reaches significance, for patients in both disease duration groups to be better at reproducing positions compared to healthy controls (Table 27). However, where significant differences existed, mean differences were small at 1.07 degrees or less. Comparison of the two disease duration groups shows no significant differences in spinal position sense with the exception of return to upright standing from sagittal flexion at L1. Here, patients with a later diagnosis are significantly more accurate than those with an earlier diagnosis (p 0.0048). Figure 14 focuses on this finding by illustrating results at L1 for this repositioning task when patients are further sub-divided into four groups on the basis of five year intervals since the self-reported start of disease. There were no significant differences in regional or angular movement between the four groups during performance of this test.

	UPRIGHT STANDING								
	SAGITTAL FLEXION			RIGHT CORONAL FLEXION			LEFT CORONAL FLEXION		
	CT	AS RCT	AS LATER	CT	AS RCT	AS LATER	CT	AS RCT	AS LATER
T1									
Mean	3.42	2.63	2.88	1.89	1.99	1.91	1.94	1.82	1.84
St. Dev.	2.34	1.25	2.23	1.14	1.28	1.17	0.91	0.85	1.06
t-tests (p)	***0.13***	**0.64**	0.33	***0.75***	**0.83**	0.95	***0.59***	**0.93**	0.68
T7									
Mean	2.36	2.04	1.89	1.80	1.58	1.44	1.77	1.66	1.54
St. Dev.	1.51	1.32	0.85	1.04	0.75	0.59	1.01	1.32	0.96
t-tests (p)	***0.38***	**0.63**	0.15	***0.37***	**0.46**	0.11	***0.67***	**0.73**	0.34
L1									
Mean	2.24	2.76	1.35	1.47	1.01	1.07	1.16	0.99	1.05
St. Dev.	1.35	1.59	0.85	1.01	0.49	0.88	0.63	0.69	0.70
t-tests (p)	***0.62***	**0.0048***	0.003*	***0.038****	**0.75**	0.10	***0.30***	**0.76**	0.50
S2									
Mean	1.51	1.48	1.53	0.43	0.36	0.32	0.34	0.44	0.42
St. Dev.	0.89	1.03	0.94	0.32	0.24	1.19	0.21	0.31	0.29
t-tests (p)	***0.51***	**0.86**	0.46	***0.37***	**0.54**	0.13	***0.59***	**0.83**	0.79
	"HALFWAY" FLEXED POSITIONS								
T1									
Mean	4.86	3.82	3.93	2.93	2.80	2.43	3.10	1.82	1.84
St. Dev.	2.81	2.31	1.95	1.65	2.35	1.35	1.53	0.85	1.06
t-tests (p)	***0.12***	**0.86**	0.13	***0.75***	**0.41**	0.27	*0.08*	**0.74**	0.19
T7									
Mean	4.37	3.41	3.66	2.54	2.35	2.06	2.56	1.66	1.54
St. Dev.	2.56	1.70	1.77	1.35	1.25	1.01	1.29	1.32	0.96
t-tests (p)	***0.37***	**0.61**	0.21	***0.56***	**0.37**	0.91	***0.01****	**0.58**	0.051
L1									
Mean	4.23	3.65	3.51	1.62	1.64	1.19	1.84	0.99	1.05
St. Dev.	2.74	1.59	1.68	0.76	0.99	0.69	1.08	0.69	0.70
t-tests (p)	***0.53***	**0.76**	0.22	*0.93*	**0.75**	0.017*	*0.30*	**0.46**	0.07
S2									
Mean	2.62	2.73	2.93	0.45	0.38	0.38	0.58	0.44	0.42
St. Dev.	1.22	1.02	1.32	0.34	0.08	0.28	0.40	0.31	0.29
t-tests (p)	***0.33***	**0.06**	0.41	***0.26***	**0.07**	0.35	*0.06*	**0.47**	0.013*

* Denotes statistical significance. Results are quoted to two decimal places. Unrelated two-sample t-test results are for comparisions between controls (CT) and AS patients with a recent (≤ 5 years, RCT, ***p values shown in italics)*** or later (> 5 years, LATER, p values shown in plain font) diagnosis and for AS patients with a recent diagnosis compared with those with a later diagnosis (**p values shown in bold**)

TABLE 27 - Position sense in upright standing and "halfway" flexed positions in controls and patients with a recent (≤ 5 years) and later (> 5 years) diagnosis of AS

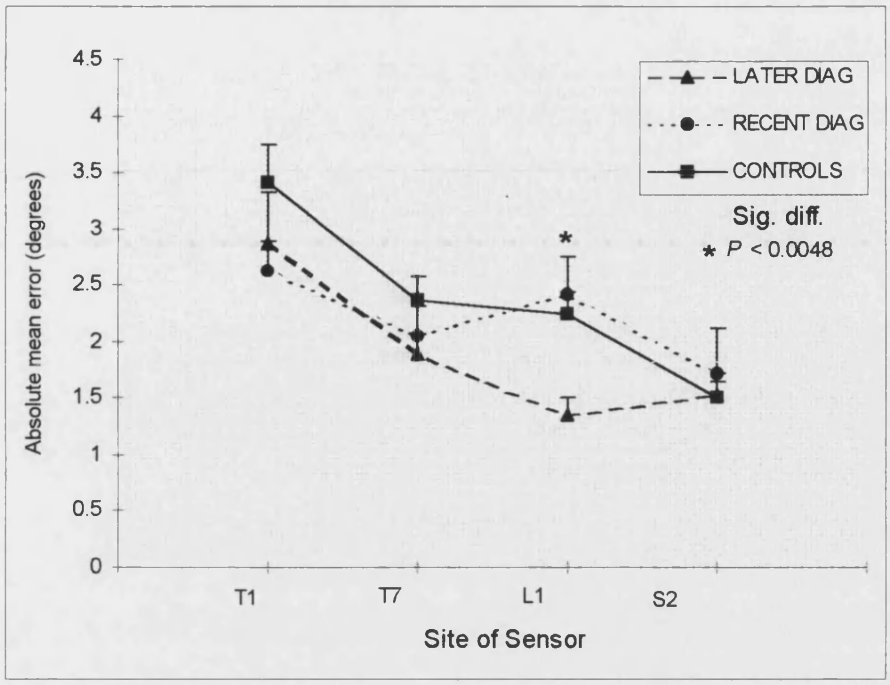


FIG. 12A - Mean repositioning error in upright standing on return from *sagittal flexion*. Patients with a recent diagnosis (≤5 years), patients with a later diagnosis (>5 years) and controls. Asterisk * denotes statistically significant difference between recent and later diagnosed patients Standard error bars included.

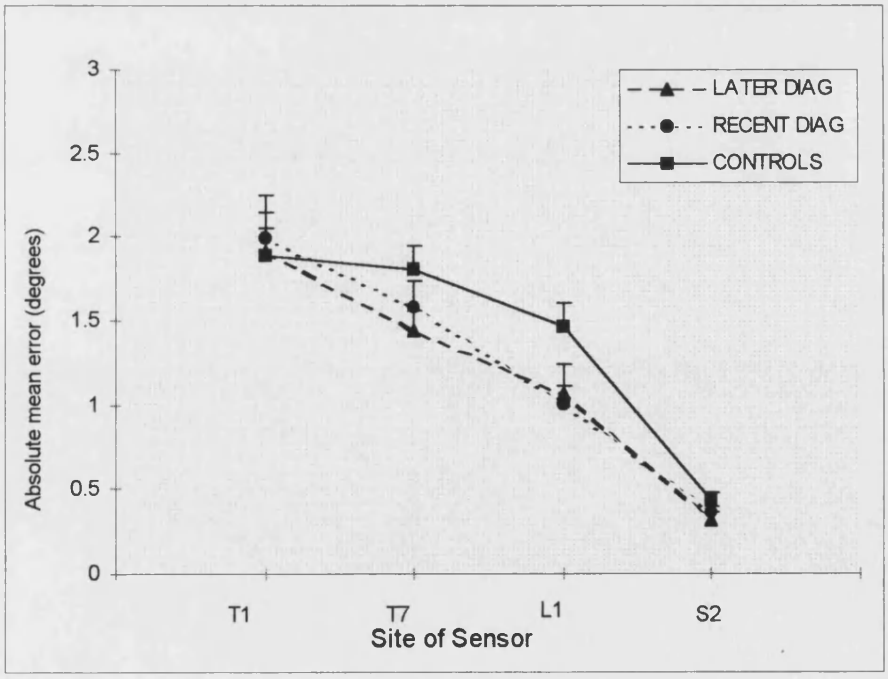


FIG. 12B - Mean repositioning error in upright standing on return from *right coronal flexion*. Patients with a recent diagnosis (≤5 years), patients with a later diagnosis (>5 years) and controls. Standard error bars included.

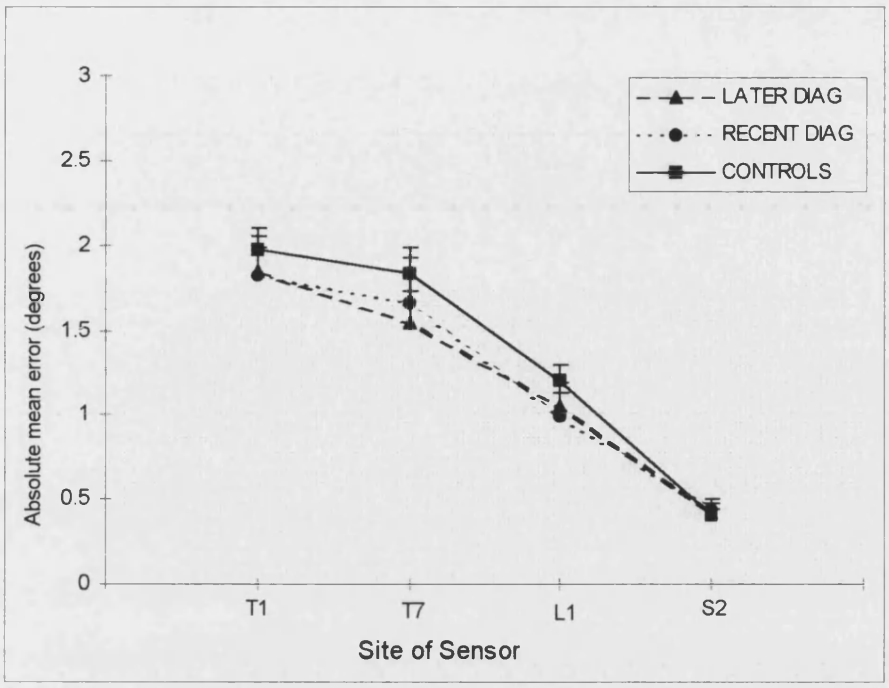


FIG. 12C - Mean repositioning error in upright standing on return from *left coronal flexion*. AS patients with a recent diagnosis (≤5 years), AS patients with a later diagnosis (>5 years), and controls. Standard error bars included.

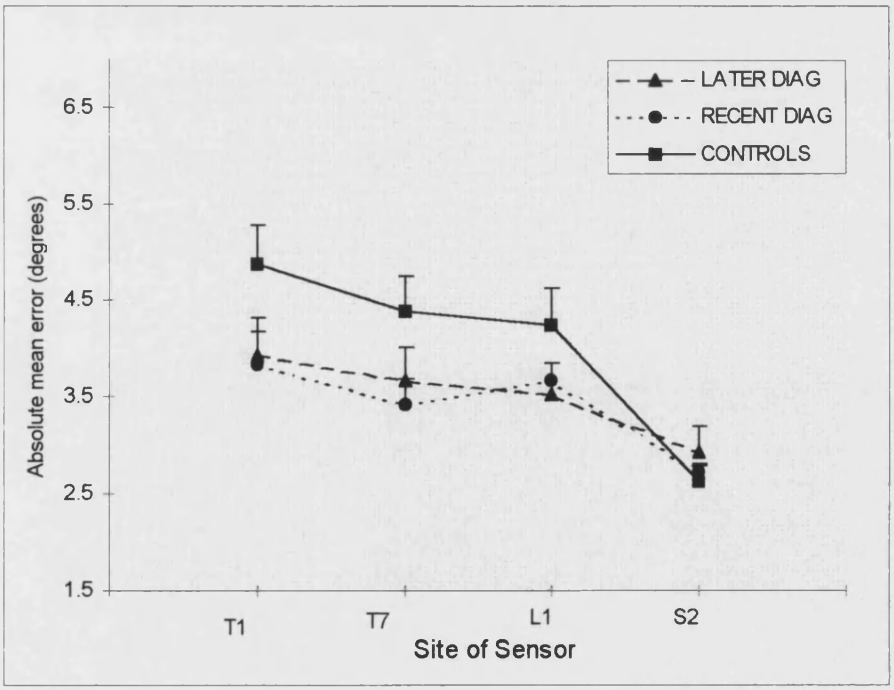


FIG. 13A - Mean repositioning error in *sagittal flexion*. Patients with a recent diagnosis (≤5 years), patients with a later diagnosis (>5 years), and controls. Standard error bars included.

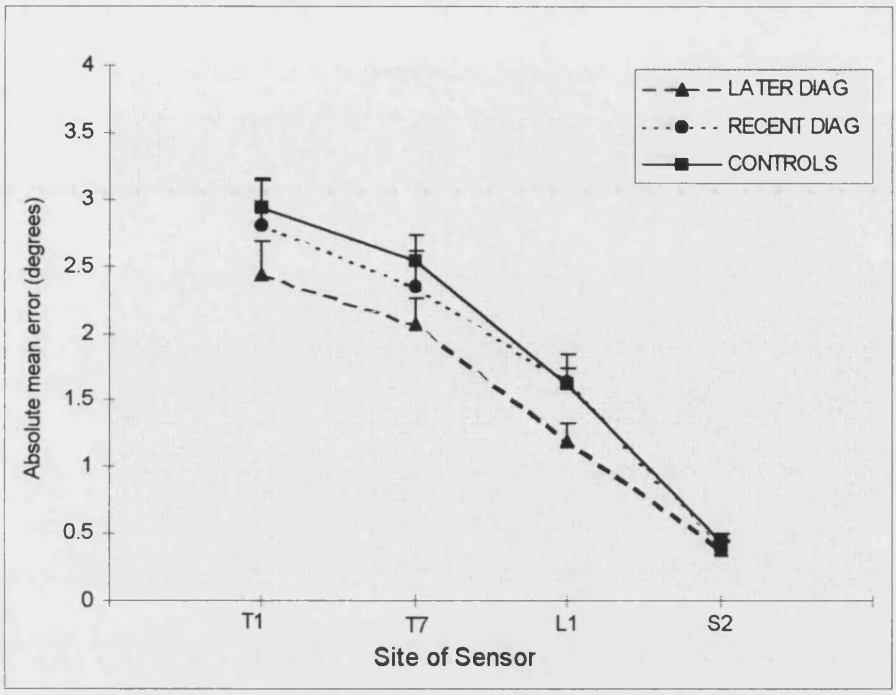


FIG. 13B - Mean repositioning error in *right coronal flexion*. AS patients with a recent diagnosis (≤5 years), AS patients with a later diagnosis (>5 years), and controls. Standard error bars included.

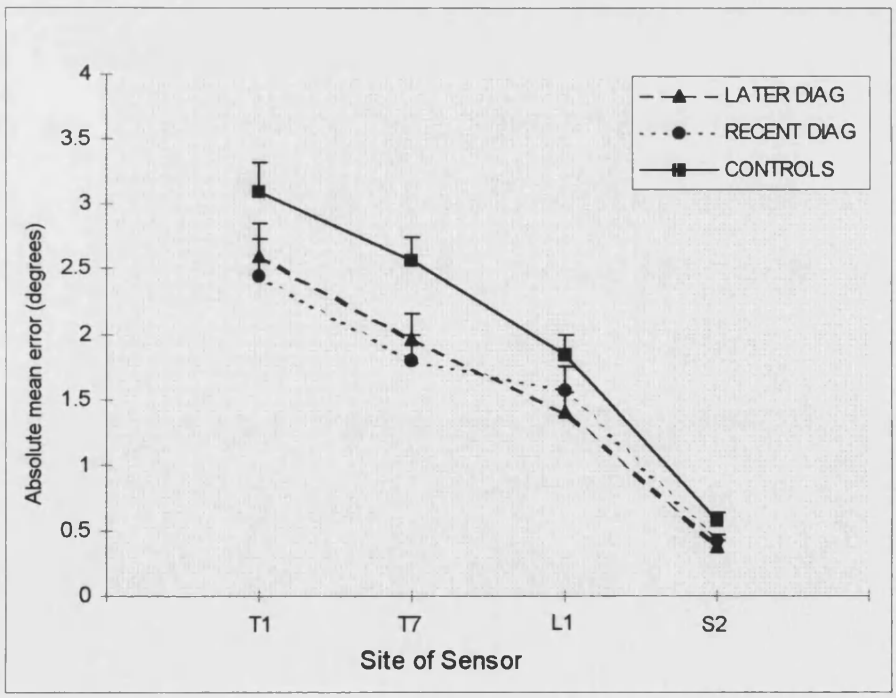


FIG. 13C - Mean repositioning error in *left coronal flexion*. AS patients with a recent diagnosis (≤5 years), AS patients with a later diagnosis (>5 years), and controls. Standard error bars included.

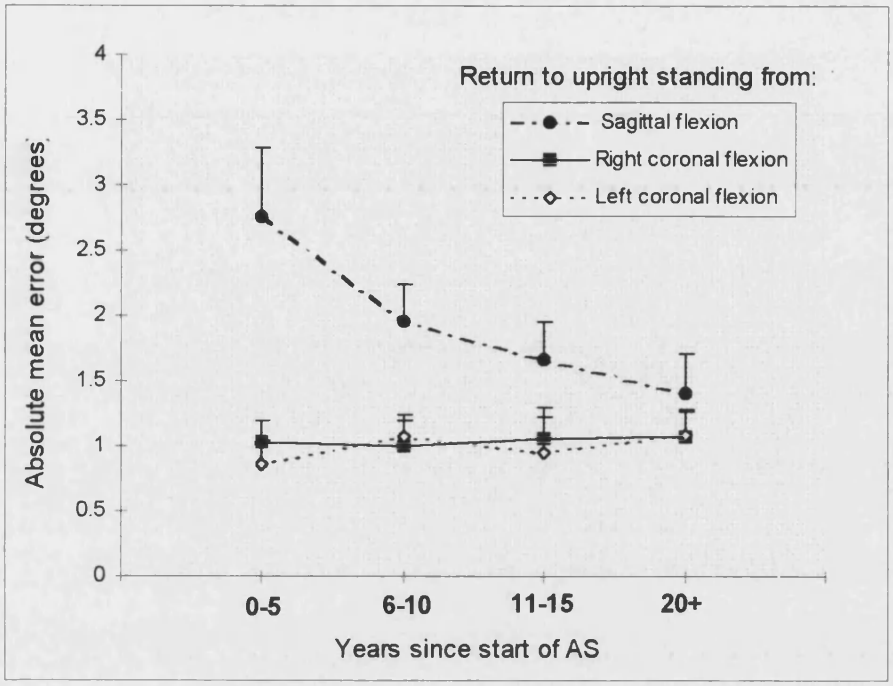


FIG. 14 - Mean repositioning error in upright standing at L1 on return from flexed positions in the sagittal and coronal plane. AS patients divided into four groups based on 5 year intervals of disease duration. Standard error bars included.

The radiographs of seven patients were identified as having been removed from filing but could not be traced. The most recent spinal radiographs of all other patients were rated by an independent scorer using the Bath Ankylosing Spondylitis Radiographic Index (BASRI - Appendix 1). Since patients may be diagnosed many years after the onset of disease, a further comparison was made between patients who had suspicious to moderate signs of radiological change (BASRI score of 1 to 3) in the lumbar spine (n = 17) and healthy controls. Results are shown in Table 28. There was an overall trend for greater accuracy in AS patients and this reached significance in one position. Mean differences between groups were small at 1.13 degrees or less.

Location of Sensor	UPRIGHT STANDING POSITIONS						"HALFWAY" POSITIONS					
	Sagittal Flexion		Right Coronal Flexion		Left Coronal Flexion		Sagittal Flexion		Right Coronal Flexion		Left Coronal Flexion	
	CT	AS LSp	CT	AS LSp	CT	AS LSp	CT	AS LSp	CT	AS LSp	CT	AS LSp
T1												
Mean	3.42	2.30	1.89	1.49	1.94	2.09	4.86	3.73	2.93	2.08	3.10	2.65
St. Dev.	2.34	1.23	1.14	0.60	0.91	1.03	2.81	2.20	1.65	1.13	1.53	1.58
t-test (p)	**0.06**		**0.17**		**0.59**		**0.14**		**0.14**		**0.81**	
T7												
Mean	2.36	1.61	1.80	1.39	1.77	1.93	4.37	3.05	2.54	1.85	2.56	1.73
St. Dev	1.5 1	0.71	1.04	0.64	1.01	1.54	2.56	1.79	1.35	1.07	1.29	1.17
t-test (p)	**0.054**		**0.14**		**0.63**		**0.05**		**0.06**		**0.02***	
L1												
Mean	2.24	1.72	1.47	1.14	1.16	1.11	4.23	3.30	1.62	1.20	1.84	1.31
St. Dev	1.35	1.43	1.01	0.86	0.63	0.95	2.74	1.69	0.76	0.83	1.08	0.81
t-test (p)	**0.18**		**0.24**		**0.82**		**0.19**		**0.06**		**0.07**	
S2												
Mean	1.51	1.40	0.43	0.28	0.41	0.50	2.62	2.31	0.45	0.48	0.58	0.41
St. Dev	0.89	0.89	0.32	0.23	0.23	0.36	1.22	1.29	0.34	0.36	0.40	0.22
t-test (p)	**0.68**		**0.09**		**0.20**		**0.52**		**0.06**		**0.08**	

* denotes statistical significance. Results are the absolute repositioning errors in degrees quoted to two decimal places. Unrelated two-sample t-test results are for differences between healthy controls (CT) and patients with lumbar radiographic change (AS Lsp)

TABLE 28 - Position sense in upright standing and "halfway" flexed positions in controls and patients with lumbar radiographic change

5.3.2.2 Range of movement

Figs.15A-15C show the mean total angular range of movement traversed to "halfway" positions at each sensor in AS patients and controls. Figs. 16A-16C show the comparable regional ranges of movement in the upper and lower thoracic spine, lumbar spine and hips. There were no significant differences between patients and controls in either total angular or regional ranges of movement in the sagittal plane. In the coronal plane, there was significantly more angular movement in controls at T1 and T7 in right coronal flexion and T1 to L1 in left coronal flexion. Comparable regional movements were similarly greater in controls; lower thoracic movement on right coronal flexion and lower thoracic and lumbar

movement on left coronal flexion. Mean differences in movement between the groups were small and less than 6.64 degrees at all positions.

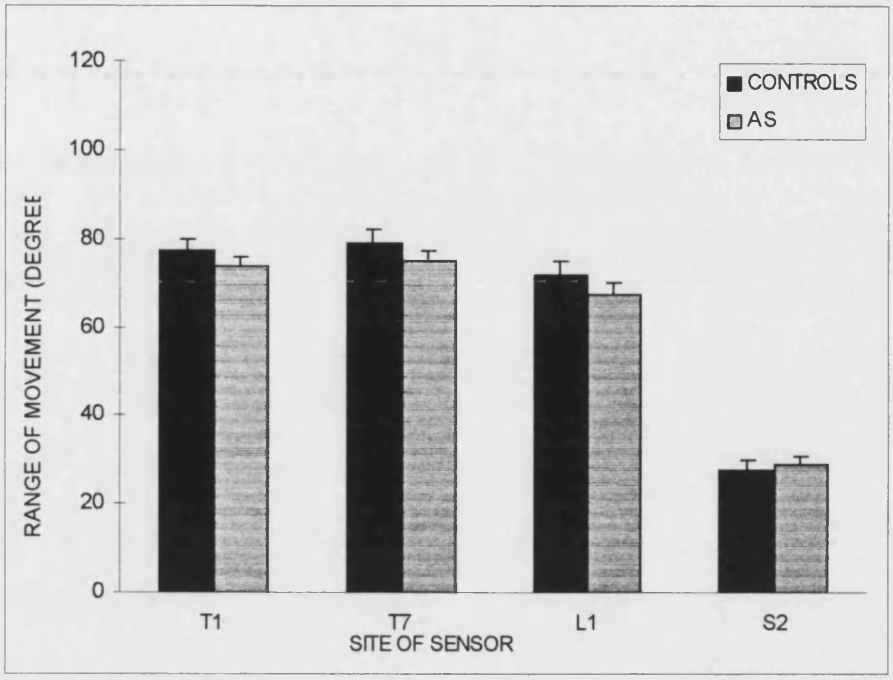


FIG. 15A - Mean angular movement traversed by sensors at T1, T7, L1 and S2 to positions in "halfway" *sagittal flexion* in AS patients and controls

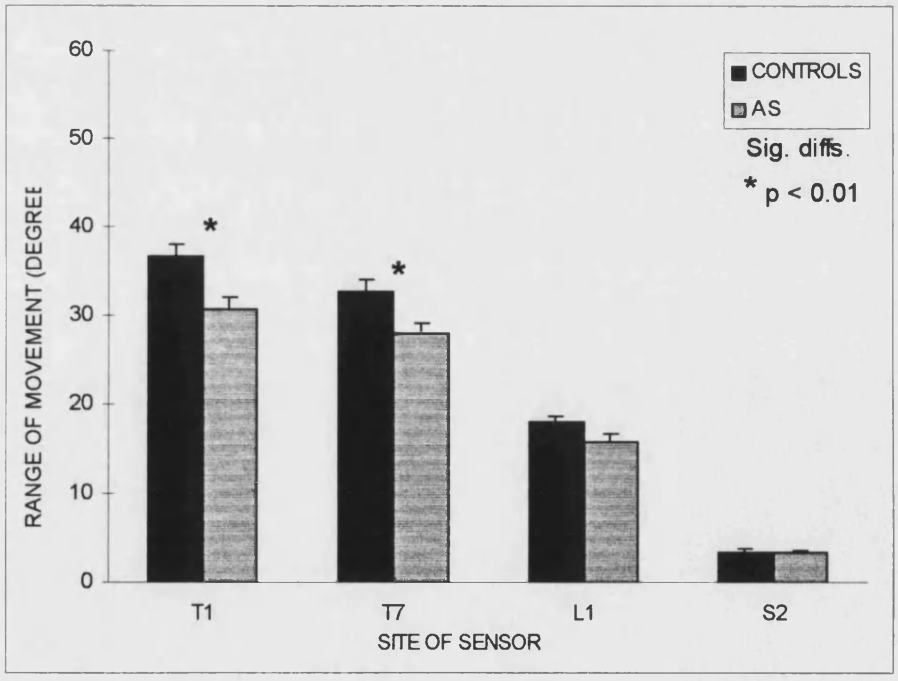


FIG. 15B - Mean angular movement traversed by sensors at T1, T7, L1 and S2 to positions in "halfway" *right coronal flexion* in AS patients and controls. *Asterisks denote statistically significant difference in range of movement between patients and controls

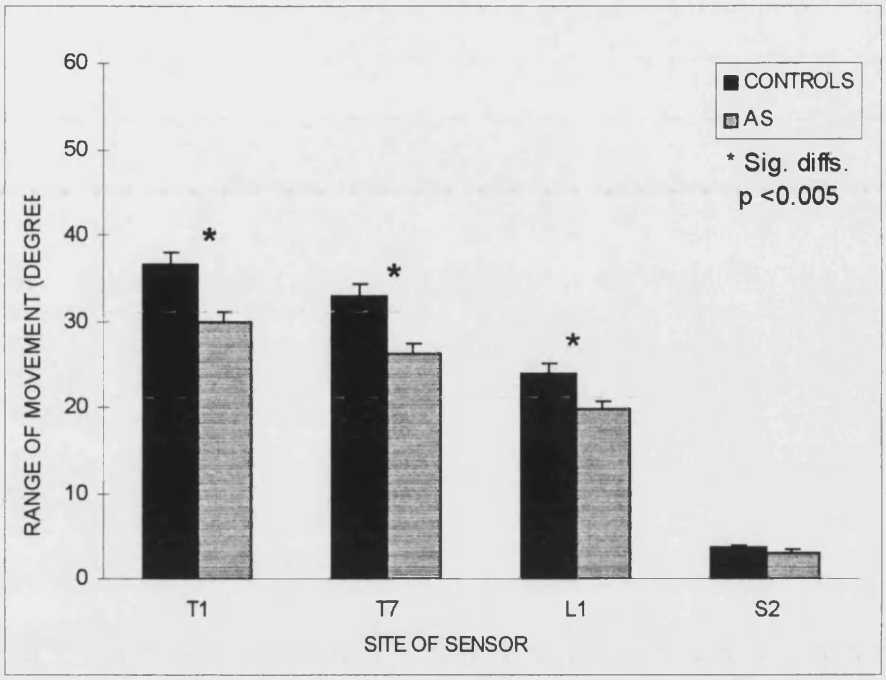


FIG. 15C- Mean angular movement traversed by sensors at T1, T7, L1 and S2 to positions in "halfway" *left coronal flexion* in AS patients and controls. *Asterisks denote statistically significant difference in range of movement between patients and controls

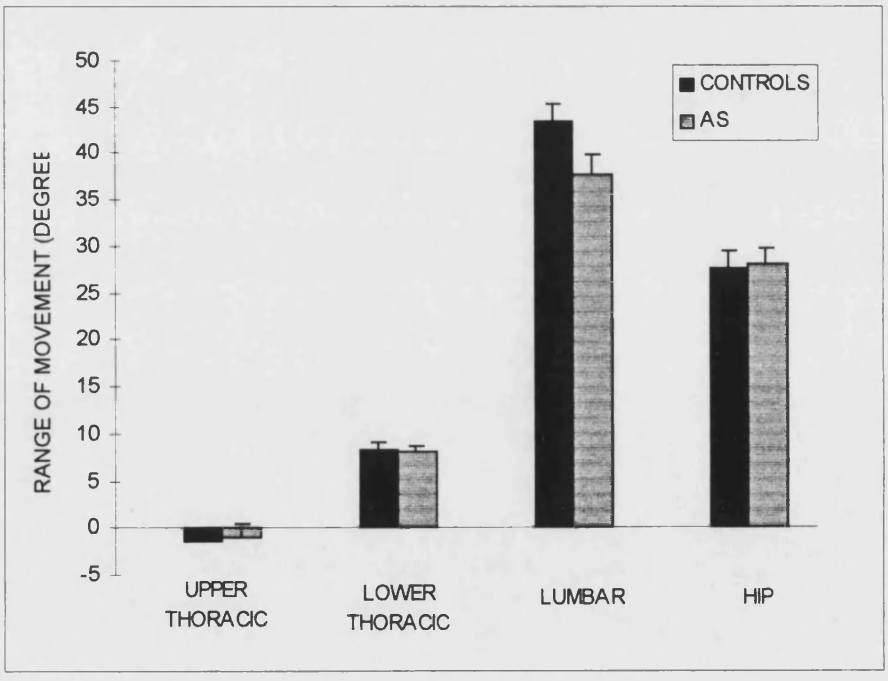


FIG. 16A - Regional range of movement in the upper and lower thoracic spine, lumbar spine and hips in AS patients and controls on "halfway" *sagittal flexion*

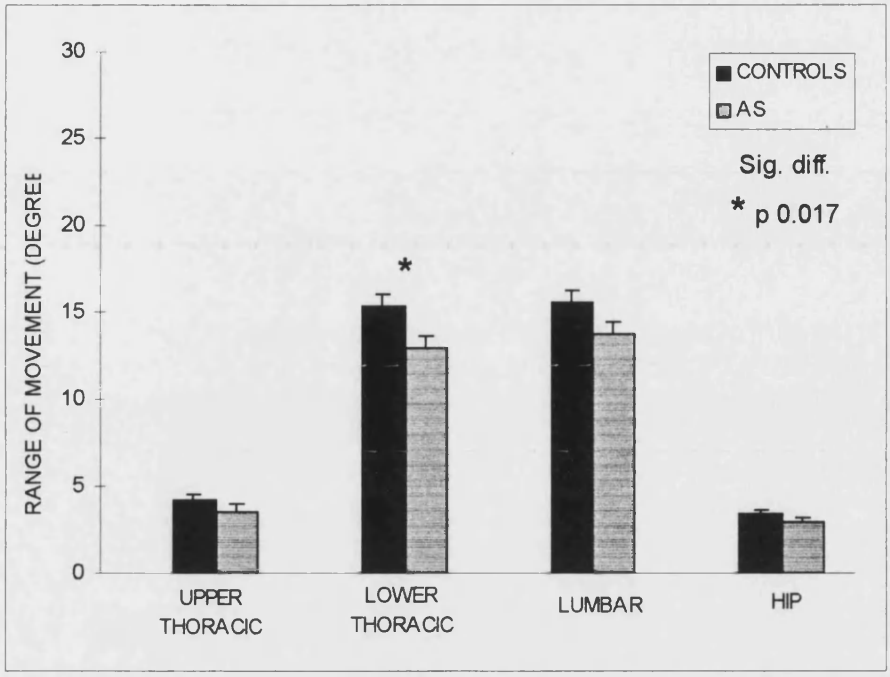


FIG. 16B - Regional range of movement in the upper and lower thoracic spine, lumbar spine and hips in AS patients and controls on "halfway" *right coronal flexion*
*Asterisk denotes statistically significant difference in range of movement between patients and controls

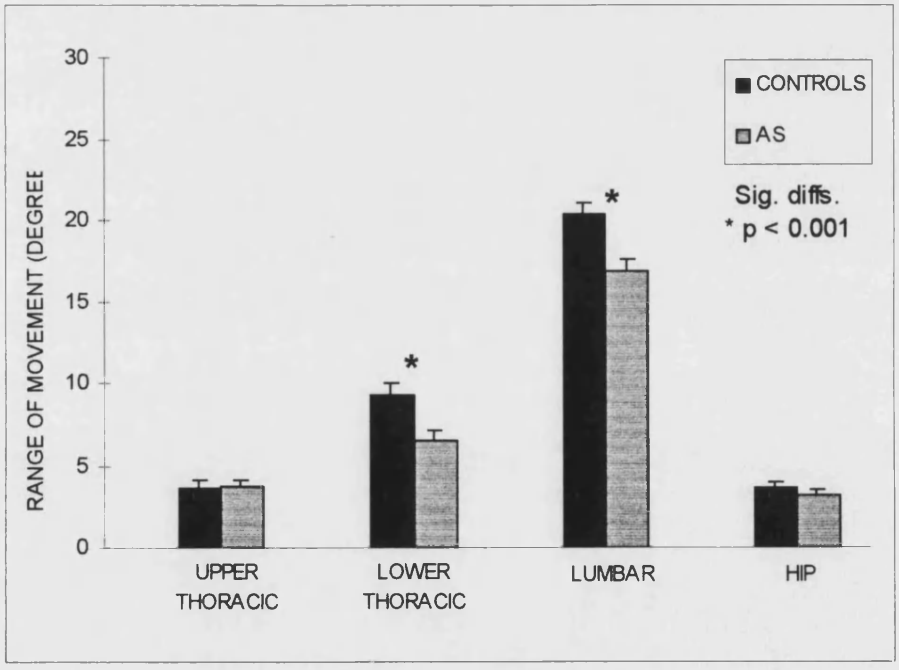


FIG. 16C - Regional range of movement in the upper and lower thoracic spine, lumbar spine and hips in AS patients and controls on "halfway"*left coronal flexion*
*Asterisks denote statistically significant difference in range of movement between patients and controls

5.3.2.3 Overshoot v undershoot of target positions

Subjects in both groups demonstrated a tendency to overshoot both upright and flexed target positions (Figs. 17A-17C, 18A-18C). This was particularly marked at T7 - S2 sites in "halfway" positions in the coronal plane (Figs. 18B and 18C). The tendency to overshoot was greater than that expected by chance in 52% of trials in flexed positions in both AS patients and controls (binomial tests, $p < 0.01$). There were no significant differences in the frequency of overshooting target positions between patients and controls (Chi-squared tests, $p > 0.05$). At T1, T7 and L1, up to 2% of trials in each position were exactly on target ("hits") in both groups. This percentage was greater at S2 in the coronal plane where between 4.7% to 8.7% of trials achieved "hits." Again, there were no significant differences in the frequency of "hits" between patients and controls.

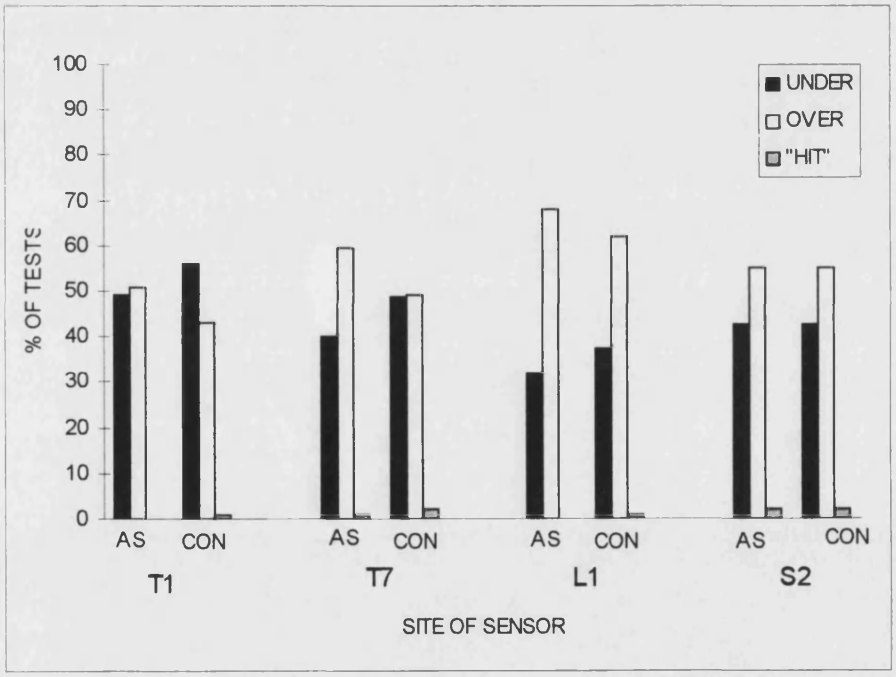


FIG. 17A - Overshoot, undershoot or exact matching of target positions ("hit") in AS patients and controls on return to upright standing from *sagittal flexion*

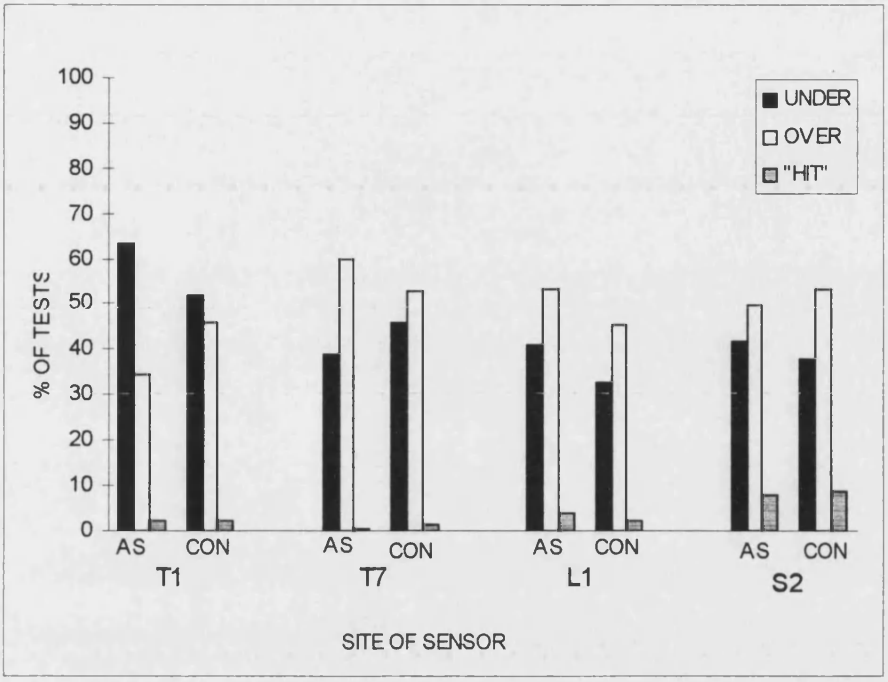


FIG. 17B - Overshoot, undershoot or exact matching of target positions ("hit") in AS patients and controls on return to upright standing from *right coronal flexion*

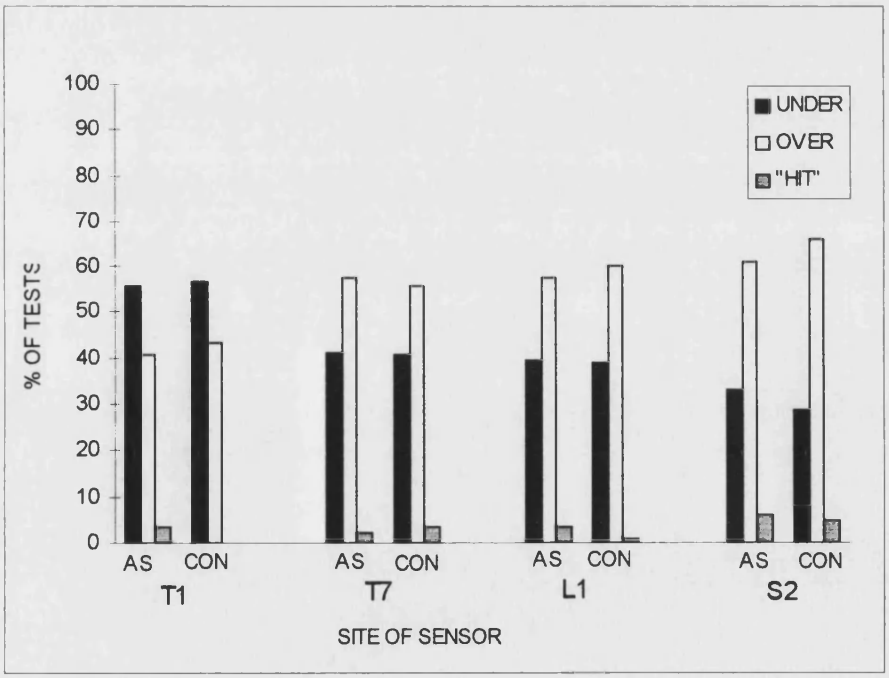


FIG. 17C - Overshoot, undershoot or exact matching of target positions ("hit") in AS patients and controls on return to upright standing from *left coronal flexion*

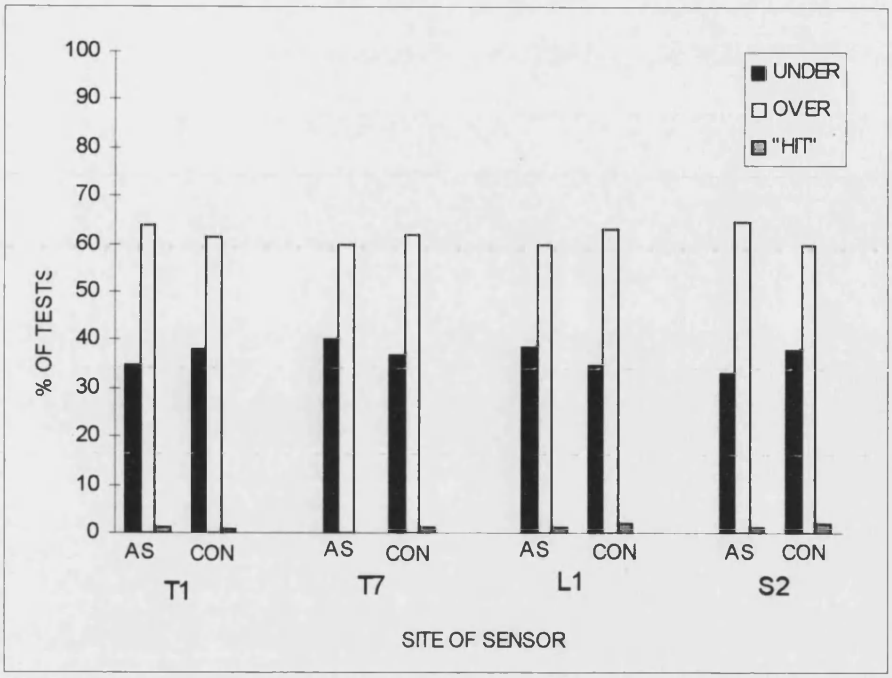


FIG. 18A- Overshoot, undershoot or exact matching of target positions ("hit") in "halfway" *sagittal flexion* at each of the sensor sites in AS patients and controls

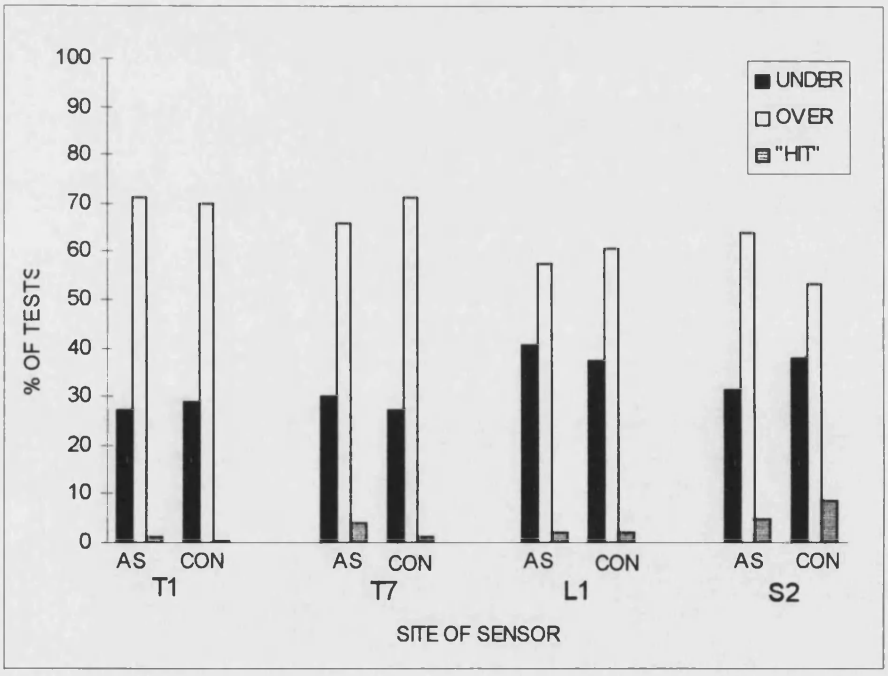


FIG. 18B - Overshoot, undershoot or exact matching of target positions ("hit") in "halfway" *right coronal flexion* at each of the sensor sites in AS patients and controls

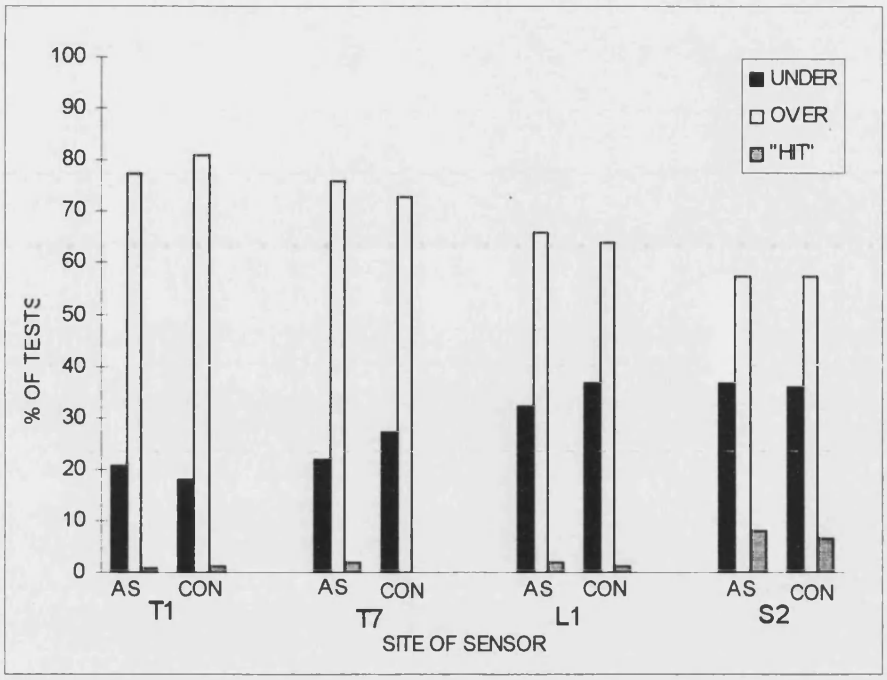


FIG. 18C - Overshoot, undershoot or exact matching of target positions ("hit") in "halfway" *left coronal flexion* at each of the sensor sites in AS patients and controls

5.3.3 Association between position sense and other endpoint measures in AS patients

5.3.3.1 Age and years since diagnosis/start of AS

Significant but weak negative correlations between repositioning error and age (r -0.44, p 0.002), years since diagnosis (r -0.35, p 0.012), and years since start of disease (r -0.31, p 0.029), were found at L1 in upright standing on return from sagittal flexion. There was no correlation between repositioning error and age or years since diagnosis or onset in positions in the coronal plane. The correlation between self-reported years since diagnosis and years since onset of disease was highly significant (r 0.81, $p < 0.001$). There was a significant weak correlation between age and the BASMI index (r 0.42, p 0.003).

5.3.3.2 Metrology and disease activity indices (BASMI/BASDAI)

Several significant but weak negative correlations were obtained between the metrology index (BASMI) and repositioning error at all sensors (Table 29). The overall trend was for

position sense acuity to improve as the BASMI index increased (ie. with more advanced disease). This trend was most consistent for "halfway" positions in left coronal flexion.

There was a weak, significant negative correlation between the disease activity index (BASDAI) and S2 repositioning error in upright standing from sagittal flexion (*r*-0.40, p 0.002), right side flexion (*r* -0.43, p 0.002), and left side flexion (*r*-0.31, p 0.028).

There was no correlation between position sense and fatigue (question 1), spinal pain (question 2) or stiffness (average score of questions 5/6) components of the BASDAI questionnaire.

POSITION	SITE OF SENSOR			
	T1	T7	L1	S2
SAGITTAL PLANE				
-Upright standing		*r*-0.37 (p0.008)		*r*-0.29 (p 0.039)
- "Halfway"			*r*-0.29 (p 0.042)	
CORONAL PLANE				
Right coronal flexion				
- Upright standing				*r*-0.35 (p 0.014)
- "Halfway"	*r*-0.44 (p 0.002)	*r*-0.36 (p 0.010)		
Left coronal flexion				
- "Halfway"	*r*-0.34 (p 0.015)	*r*-0.40 (p 0.004)	*r*-0.33 (p 0.020)	*r*-0.38 (p 0.007)

TABLE 29 - Statistically significant Pearson correlation coefficients (*r*) between absolute mean repositioning error and the metrology index (BASMI)

5.3.3.3 Functional and Global indices

There was a correlation between repositioning error at S2 on return from right side flexion and the functional index (BASFI) (*r* -0.4323, p 0.002) and global disease index (BASG-1) (*r* -0.316, p 0.026). There was no correlation between functional and global indices at any other sensor level.

5.3.4 Association between position sense and age in controls

There was a weak but positive association between age in years and repositioning error at L1 in upright standing on return from right side flexion (r 0.374, p 0.007).

5.4 DISCUSSION

5.4.1 Patient selection

Patients in this study had low metrology (BASMI) scores and were therefore in a mild stage of disease. Clinical change predates radiological change, often by many years. Postural changes, such as reduction of the lumbar lordosis may occur relatively early in the disease process and often before radiological changes are apparent. In fact, during the BASRI rating procedure, flattening of the normal lumbar lordosis was observed to be interpreted by raters as indicative of AS in the absence of other radiological change. The relevance of any difference in spinal position sense in AS patients in comparison with healthy controls is most compelling in this mild stage of disease when postural changes may occur and before more advanced changes, such as incipient spinal fusion, are evidenced. Although the correlation between time of diagnosis and patients perception of the time of disease was good (r 0.80, p <0.0001), the time lapse between diagnosis and self-reported start of the disease was, on average, 5.32 years. This equates with the difficulties in diagnosis which are a feature of this disease. In this study, all patients were diagnosed using the modified New York criteria (van der Linden 1984) and had radiographic evidence of sacroiliac involvement. The patient group was also subdivided on the basis of radiographic change and disease duration to assess the affects of more advanced disease on position sense and the implications of these findings are discussed later in this section. Regional, as well as global, input from afferent populations contributes to spinal position sense. It is therefore important that this dimension of spinal position sense is challenged both by the repositioning task itself and by the selection of patients with a capacity for spinal movement. Although 1% of patients may remain in remission for two or more years (Kennedy et. al. 1993), the majority of AS patients demonstrate disease progression with time. The association between position sense and posture in AS is investigated in Chapter 7 when patients in this comparative study were reassessed at a later stage of disease progression.

5.4.2 Reliability of position sense measurements

5.4.2.1 Comparison of patients and controls

As reported for controls (Chapter 3), the technique provided reliable position sense measurements in AS patients at L1 and S2 in upright standing on return from sagittal flexion. Similarly, reliable results were found at T1, T7 and L1 in upright standing on return from right side flexion. The associated standard errors of measurement (SEM) were small and lay between 0.45 to 0.64 degrees in patients and 0.14 to 0.79 degrees in controls. "Halfway" repositioning errors in sagittal flexion, however, had poor within-day and day-to-day intra-class correlation (ICC) in patients compared to controls. The ICC is a proportional index which is essentially calculated as the ratio of between subject variance to the total variance (Bland and Altman 1990, Keating and Matyas 1998). The low ICC's in patients in sagittal flexion reflected the proportionately larger variability of measurements within patients compared to the variability of measurements between patients. The low ICCs of position sense measurements in "halfway" sagittal flexion in patients therefore indicated that these measurements had a poor capacity to discriminate between AS patients.

Unlike controls, patients demonstrated moderate to good reliability of position sense measurements in upright and "halfway" positions at T1-L1 sites in the left coronal plane. This indicated that these positions had good discriminatory quality between patients. As found previously in controls (Chapter 3), the small range of repositioning errors at S2 in the coronal plane returned low ICC's at this sensor site and repositioning errors approached the standard error of measurements recorded here.

5.4.2.2 Comparison with other reliability studies of spinal position sense

Only one other study appears to have assessed the reliability of spinal position sense measurements in a patient population. Gill and Callaghan (1998), report an intraclass correlation coefficient of R 0.85 for upright lumbar positions on return from sagittal flexion. This equates with the finding of R 0.92 in this current study. No studies could be found which specifically assess the reliability of measurements in flexed positions in patients. Field et. al. (1991), however, report decreased variability in lumbar position sense in sagittal flexion in patients with back injuries compared to healthy controls. Results are published in

a short abstract which omits any original data. The abstract however, suggests that the results equate with those of the current study which also found less variability of L1 measurements in sagittal flexion in patients compared to controls. This is reflected in the lower standard deviation and greater precision (SEM: 0.93° patients: 1.63° controls) of measurements at L1 in sagittal flexion in patients compared to controls. Similarly, as explained previously, the lower day-to-day ICC in patients is largely attributable to the smaller variation in measurements between patients at L1 in sagittal flexion compared to controls.

5.4.3 Comparison of spinal position sense in AS patients and controls

Patients with ankylosing spondylitis demonstrated better proprioceptive acuity than healthy controls in 75% of positions. Similarly, patients with signs of AS on lumbar radiographs were slightly more accurate than controls in 83% of positions. Differences between patients and controls achieved statistical significance in one upright and three "halfway" flexed positions and mean differences amounted to less than one degree. They are therefore unlikely to be of any functional significance. Furthermore, with one exception, (T7 on left coronal flexion), positions which showed significant differences were also associated with poor reliability of results in controls. Like controls, patients demonstrated a trend towards better position sense acuity from cephalad to caudad sites and in upright compared to flexed positions. Similarly, qualitative aspects of proprioception were comparable for both groups. Patients and controls tended to equally overestimate target positions, particularly in the coronal plane.

Subdivision of AS patients into two groups on the basis of years since diagnosis showed no significant difference in repositioning error between the groups with the exception of measurements at L1 on return to upright standing from sagittal flexion. In this position, which demonstrated good reliability in both patients and controls, patients diagnosed longer showed a statistically significant improvement in spinal position sense compared with patients diagnosed for a shorter period. Similarly, there was a difference between controls and patients with a later diagnosis (> 5 years) in "halfway" sagittal flexion. Mean differences were 0.89 and 1.41 degrees respectively. They lay within the 95% confidence limits of the

standard error of measurement in this position and are unlikely to be of functional significance.

Further subdivision of patients into smaller cohorts on the basis of disease duration revealed an underlying trend of improvement in proprioceptive acuity at L1 with increasing disease duration. This trend may reflect the small range effect found in a previous study (Chapter 4) where there was a significant difference of 0.73 degrees in upright standing repositioning error at L1 on return from small "one-third" and larger "two-thirds" movements into sagittal flexion. This is unlikely, however, since differences in the total angular or regional range of sagittal flexion traversed by the AS sub-groups during upright repositioning tasks were small and did not achieve statistical significance. The trend towards better position sense at L1 in patients with more advanced disease was therefore unlikely to be attributable to range effects.

5.4.4 Comparision with other patient studies

The few studies of spinal position sense that have been conducted on patients (Loudon et.al. 1997, Revel et. al. 1991, 1994, Gill and Callaghan 1998) found significant differences between patients and controls. Patients with chronic low back pain were, on average, 2.3 degrees less accurate in actively repositioning the lumbar spine in midline postures compared with healthy subjects (Gill and Callaghan 1998). A similar deficit of 2.4 degrees was reported in patients with cervical pain compared with heathy controls (Revel et. al. 1991). A somewhat larger deficit of 3.26 degrees between patients with whiplash injury and controls has also recently been found by Loudon et. al. (1997) using a cervical goniometer. The findings of these spinal studies reinforce the popular belief, which originated from peripheral joint studies, that disease involvement of afferents conveying proprioceptive information causes a clinically significant deficit in position sense.

This study of spinal position sense, however, found that there is no deficit in spinal position sense in ankylosing spondylitis patients with mild disease. Indeed, there is some indication that position sense in these patients may be slightly superior to that of controls.

Only four patients reported discomfort in "halfway" positions (rated 3-4/10 in intensity) and these were in coronal flexion. While this may, therefore, have been a factor in improved coronal acuity in patients, the lack of significant correlation between spinal pain and position sense suggests that nociceptive input is unlikely to have made any major contribution to position sense. Peripheral studies of other inflammatory pathologies, such as osteoarthritis, similarly report no association between proprioception and pain (Skinner et. al. 1984, Sharma et. al. 1997). A further factor to consider is that there was significantly less angular and regional movement in patients at some at some sites/regions in "halfway" positions in coronal flexion. Mean differences were, however, small and a previous study suggests that there is no association between position sense and magnitude of movement (Chapter 4).

5.4.5 Association of position sense with other endpoint measurements in patients

The significant positive correlation between age and the BASMI index (r 0.416, p 0.003) is compatible with the progressive nature of AS. Several weak, negative correlations (Table 30) suggested an association between the metrology index (BASMI) and position sense. Patients with higher BASMI indices tended to have better position sense acuity. Significant correlations at sites with moderate or good reliability of repositioning measurements in patients included T1- L1 in left side flexion and S2 in upright standing from sagittal flexion. The combination of these significant negative correlations, moderate to good intraclass correlation coefficients in the left coronal plane, and significant or almost significant differences between patients and controls suggests slightly superior position sense acuity in the left coronal plane in patients. Again however, mean differences were very small at 0.68 degrees or less, and lay within the 95% confidence limits determined by the standard error of measurement for controls at this position.

A significant association between the Bath AS Disease Activity Index (BASDAI) and position sense was found in left and right coronal flexion and upon return from sagittal flexion, but only at the sacral sensor location. These two coronal positions demonstrated low measurement reliability in patients and controls. This equates with findings in the previous reliability study (Chapter 3) where low ICCs at S2 in the coronal plane reflected the small range of measurements and their low variability between patients. In the sagittal

plane, the association between BASDAI and position sense was again weak but statistically significant (*r*-0.421, p 0.002), with position sense acuity improving with disease activity.

Further weak but significant negative correlations between position sense and age, and position sense and disease duration, were found in sagittal flexion at two sensor locations, T7 and L1. One of these sites, T7, however, demonstrated poor reliability of measurements in patients. The remaining site, L1, was found in an earlier study (Chapter 4) to be subject to a small range effect. Older patients tend to have had AS longer than younger patients and therefore generally have less spinal movement. The tendency for improved position sense with increased age and disease duration at L1 may therefore reflect small differences in the range of movement traversed during testing rather than an age related association per se.

5.4.6 Explanation of the findings of this study

There are several possible explanations for the lack of any substantive difference in spinal position sense between patients and controls. Firstly, there may indeed be a deficit in proprioceptive input from affected entheses but one which is compensated for by input from other unaffected structures such as muscle afferents. A second possibility is that pathological processes in AS do not result in proprioceptive deficits. Conversely, pathological processes may actually help to enhance spinal position sense in patients thus accounting for the trend towards greater acuity in this group. These explanations will be discussed in turn in the following two sections of this discusssion.

5.4.6.1 Compensatory mechanisms

The first explanation involves the possible compensation of any deficits attributable to direct involvement of afferents in the disease process. Anatomically, muscles, ligaments and fascia tend to be organised in series as one continuous structure so that consideration of these components as separate units for the purposes of proprioceptive input may not be appropriate. The capacity for compensation within the proprioceptive system may be sufficient to accomodate the removal of entire joints without deficits in position sense (Barrack et. al. 1983, Stender and Drowatzky 1994, Ischii et. al. 1997). Similarly, several

peripheral studies have shown that injury or anaesthesia of ligaments may not affect position sense (Friden et. al. 1997, Konradsen et. al. 1993). Studies which have reported significant effects due to ligamentous damage or joint replacement have sometimes used controversial techniques based on reflex aspects of proprioception (Beard et. al. 1993) or methods which have not been assessed for reliability (Barrack et. al. 1989). Other studies have demonstrated an effect but only on movement sense (Garn and Newton 1988, Barrack et. al. 1989, Friden et. al. 1997). The results of both types of study are often difficult to assess because statistical power is frequently compromised by small subject numbers. In addition, movement sense tests appear to activate slowly adapting joint afferents while position sense protocols recruit both slow and fast adapting joint afferents and muscle afferents. They are therefore more likely to reflect changes in the proprioceptive contribution of these receptors rather than the cumulative contribution of all receptor populations activated by normal, functional movement.

Although there is some debate concerning muscle changes in AS, there are no reports of involvement of muscle spindles (Chapter 1, pp. 49-50). Muscle spindles have been found in paraspinal musculature (Amonoo-Kuofi 1982, Ford et. al. 1988, Yamashita et. al. 1993) and particularly high concentrations have been reported in small, short paraspinal muscles which cross only one vertebral level (Nitz and Peck 1986). The small size and short leverage of these muscles suggests that they may serve as proprioceptive monitors rather than play any substantial role in movement (Nitz and Peck 1986). Vibration of these afferents has also recently been shown to produce a muscle lengthening illusion in normal subjects (Brumagne et. al. 1999). Input from the rich concentrations of muscle spindles in these small muscles may contribute to spinal position sense and, in particular, serve to compensate for any deficits from joint structures.

A further potential compensatory mechanism relevant to spinal proprioception is input from the vestibular apparatus. Vestibular input has been described as a major force in the maintenance of upright posture (Markham 1987) and may account for the superior position sense found in this posture in both patients and controls. Whether vestibular or proprioceptive input predominates is debatable and this may vary under different test conditions. Experiments on seated subjects, for example, suggest that proprioceptive input predominates when the feet are perceptually stationary (Hlavacka et. al. 1992). Vestibular

input has been considered a confounding factor in the study of spinal proprioception (Taylor and McCloskey 1990, Gill and Callaghan 1998). It is, however, inevitable during normal spinal movement. Taylor and McCloskey (1990) controlled for vestibular input by assessing spinal position sense by rotating the trunk about a fixed head and shoulders in sitting. They found no difference in position sense in healthy subjects in this test compared to one in which the reverse condition, combined head and trunk movement, applied. Only one study appears to have attempted to manipulate vestibular input in a spinal position sense study involving patients. Gill and Callaghan (1998) tried to reduce the vestibular contribution by assessing spinal position sense in four point kneeling. Using the lumbar motion monitor, they reported a small, non-significant, improvement in position sense accuracy in low back pain patients and controls in standing compared to kneeling. There is some possibility that the slightly improved accuity in standing might be due to an enhanced contribution from the vestibular system but the extent to which kneeling might reduce vestibular input is not immediately obvious. The ability of the vestibular system to compensate for local proprioceptive deficits in the spine has, therefore, yet to be precisely determined. Input from the system is, however, an inevitable part of normal spinal movement and attempts to control it may not represent naturalistic conditions.

Proprioceptive input from the lower limbs and soles of the feet is inevitable during standing conditions and may compensate for local spinal proprioceptive deficits. Subjects were asked not to bend their knees during tests to control for cues to spinal position from knee flexion. In addition, those with a history of leg trauma, which might affect proprioception, were excluded from the study. Experiments involving the perception of horizonal displacements of the trunk or feet in sitting suggest that trunk and leg proprioception are interrelated (Hlavacka et. al. 1992). These authors proposed a proprioceptive model in which trunk position was related to the feet and head position related to the trunk. As with vestibular input, the compensatory potential of proprioceptive input from the legs in standing conditions, is relatively unexplored. No studies appear to have assessed spinal position sense in sitting compared to standing.

Spinal position sense may derive from other sources. The lack of regional generalizability of proprioceptive input is most evident in the hand where cutaneous input appears to be particularly important in maintaining proprioceptive accuity (Grigg 1994). Cutaneous input

may be important, particularly during coronal flexion. Several patients and controls reported that skin contact during side flexion was helpful in the repositioning task. Both patients and controls demonstrated superior position sense in coronal flexion compared to sagittal flexion. Position sense in coronal flexion, however, has previously been shown to be independent of range effects (Chapter 4). If cutaneous input were important in this position, greater accuity would be expected at positions further into the range where skin-on-skin contact would be greater.

Extraneous input from the attachment of sensors to the skin does not appear to have influenced results. No subject reported receiving cues from these sites. Furthermore, the position in which input might be considered maximal due to stretch, sagittal flexion, demonstrates less position sense accuity in comparison with other positions.

5.4.6.2 Pathological considerations

Apophyseal joints, spinal entheses, para-and inter-spinal ligaments have all been found to contain low threshold afferents capable of a mechanosensitive function (McLain and Pickar 1998, Yahia et. al. 1988, Yamashita et. al. 1990, McLain 1994). The function of afferents sited at the antero-lateral junction of the annulus fibrosis to the vertebral body, a common site of involvement in AS, is, however, less certain. These afferents have high stimulation thresholds and may therefore be primarily nociceptive, rather than proprioceptive (Yamashita et. al. 1993). On the whole, however, common sites of pathological involvement in AS appear to contain afferents which convey proprioceptive information.

In a recent quantitative study of mechanoreceptor endings in human thoracic and lumbar facet joints (McLain and Pickar 1998) it was found that receptor populations in these joints were inconsistent and sparse in comparison with the cervical spine. This suggests that receptors have a large receptive field and that proprioception is less refined in these regions compared to the cervical spine. It is also possible that these receptors are mainly protective in function and are therefore only active at the extremes of range. McLain and Pickar (1998) found that only forty percent of thoracic and sixty percent of lumbar facet joints contained mechanoreceptors. The sparse innervation of the thoracic spine, in particular, is consistent with the intrinsic stability and relative immobility of this region. The relative

paucity of receptors in the thoracic spine may underlie the trend for position sense acuity to diminish between S2 and T1.

It is possible that inflammatory processes in AS may, in fact, sensitise proprioceptive afferents in facet joints by stretching the joint capsule. There is some evidence, for example, that effusion in synovial joints enhances proprioception. McCloskey et. al. (1985) report an improvement in movement sense accuity following the injection of dextran into healthy synovial finger joints. This was, however, a small study on three subjects and the regional specificity of proprioceptive processing, particularly in the hand, makes it difficult to translate findings from one region to another. Experiments on the cat knee joint have, however, shown that acute inflammation sensitises articular afferents and makes them more responsive to normal movement (Schaible and Schmidt 1985). Although the majority of patients were on non-steroidal anti-inflammatory drugs, a degree of active spinal inflammation would be expected to be present. Acute inflammation in synovial joints may also sensitise afferents by other, non-mechanical, means. Little appears to be known about this aspect but sensory nerves within synovial joints may contribute to joint inflammation via chemical mediators. A two-way communication between sensory afferents and inflammatory cells may actually serve to sustain inflammatory processes within joints (Scott et. al. 1994).

Patients showed a trend towards better position sense compared to controls and this reached statistical significance in the coronal plane. The small differences reported are, however, unlikely to be of any functional significance and no association was found between function and position sense. Clinically, reduction of coronal flexion is a relatively early feature of AS and this reflects the involvement of lumbar intervertebral and synovial apophyseal joints in the disease process. Coronal flexion, which occurs mainly in the lumbar region, involves simulataneous compression of structures on one side of the trunk and stretching of the opposite side. It is possible that structures, notably apophyseal joints, are sensitised by inflammation in AS and that this may underlie the trend towards improved position sense acuity in patients particularly in the coronal plane. Further work needs to be carried out to assess the effects of inflammatory processes on clinical tests of position sense. The current study suggests the possibilility of sub-clinical proprioceptive enhancement as a consequence of the inflammatory process in AS.

Changes in the sensitivity of muscle spindles may also underlie the trend towards better position sense acuity in patients. Tensing the muscles around a joint enhances the stretch sensitivity of muscle spindles and has been shown to improve joint position sense (Gandevia and McCloskey 1976). This effect appears to be directly related to the contribution of muscle afferents rather than an indirect effect on other afferent populations (Grigg 1994). It may equate with the finding that soft tissue balancing and ligament retensioning procedures improve proprioception in the knee (Attfield et. al. 1996). The contribution of muscle afferents during functional voluntary movement has also been shown to improve performance in position matching tasks (Ecklund 1972, Swinkels et. al. 1995). It is therefore possible that reflex protective muscle contraction, "muscle spasm", due to pain in AS (Waragai and Shinotoh 1994, Calin et. al. 1993), may contribute to enhanced position sense in patients.

The majority of clinical studies on peripheral proprioception which report differences between patients and controls have been conducted on degenerative rather than inflammatory conditions. The few spinal studies on patients are based on generic spinal pathology such as low back or cervical pain (Revel et. al. 1991, Gill and Callaghan 1998). In several respects, pathological processes in AS most closely resemble those of rheumatoid arthritis (Ball 1971). Only one study, however, has assessesed position sense in this condition and this was in the proximal interphalangeal joint. Here, Ferrell et. al. (1992), found only qualitative differences in position sense with patients tending to overestimate target positions when compared to controls. This was a small study of ten patients and, as discussed previously, it may not be appropriate to make inferences from the results of a single joint task in the hand to a multiple joint task in the spine. No qualitative differences were found in spinal position sense in the current study and both groups tended to equally overestimate target positions in flexion.

5.5 SUMMARY

There were no clinically significant quantitative or qualitative differences in spinal position sense between healthy controls and ankylosing spondylitis patients with mild disease. Subdivision of the patient group on the basis of radiographic change or disease duration similarly revealed no clinically significant differences. There was a trend for patients to demonstrate slightly better position sense acuity compared to controls and this reached statistical significance in left coronal flexion. This may reflect an enhanced contribution from position sense afferents related to disease processes. This possibility is supported by weak but significant associations between repositioning accuracy and disease activity (BASDAI) and metrology (BASMI) indices in some positions. Significant correlations with other endpoint measures do not suggest any substantive association with position sense. Spinal position sense is unlikely to be a useful endpoint measure in patients with ankylosing spondylitis.

CHAPTER 6

THE EFFECT OF AN IN-PATIENT PROGRAMME ON SPINAL POSITION SENSE AND OTHER ENDPOINT MEASURES IN PATIENTS WITH ANKYLOSING SPONDYLITIS

6.1 INTRODUCTION

Exercise is considered important to the successful management of AS and there is some evidence for the short-term efficacy of exercise-based programmes in improving posture, function and mobility (Chapter 1, pp. 62-71). As previously discussed (pp. 40-41), the association between position sense and other endpoint measures remains relatively unexplored. The clinical implications of small but statistically significant differences in proprioception between patients and healthy controls, such as those reported in previous studies, are therefore unknown. Two recent studies of knee proprioception following a proprioceptive exercise programme suggest that increased proprioceptive acuity is associated with improvements in function (Beard et. al. 1993, 1994a). However, although these studies used a validated score of knee function, proprioception was assessed by the controversial technique of reflex hamstring contraction latency (Chapter 1 p. 26). There are no published studies which investigate the relationship between changes in spinal position sense, function and other endpoint measures following exercise intervention in a patient population.

This chapter describes an experiment to assesses spinal position sense and other endpoint measures in a group of patients with early AS before and after an established intensive in-patient programme at the Royal National Hospital for Rheumatic Diseases, Bath, UK. This programme has recently been associated with statistically significant improvements in indices of function (BASFI), metrology (BASMI), disease activity (BASDAI) and global well-being (BASG-1) (Appendix 1). The programme incorporates a wide variety of stretching and other forms of mobilising exercise, reflecting the contemporary emphasis on relatively specific, low-impact, soft tissue mobilising exercise in AS. The exercise component of the programme is primarily designed to increase range of movement by elongating soft-tissues which have adaptively shortened in response to inflammation, postural deformity and limited range of movement (Kisner and Colby 1990). However, although not specifically designed to rehabilitate proprioception, some of the exercises in

the programme have previously been advocated for peripheral or spinal proprioceptive rehabilitation. Examples are closed chain exercises and those involving balance or co-ordination (Appendix 4).

Only two examples of training programmes which purport to target spinal proprioception are described in the literature (Norris et. al. 1995, Johannsen et. al. 1995). As in peripheral joints, these spinal programmes incorporate dynamic co-ordination and balancing exercises of increasing complexity (Johannsen et. al. 1995, Hoffman and Payne 1995). No studies have been reported which assess the effect of these or equivalent programmes on spinal proprioception. Johannsen et. al. (1995), however, compared their "co-ordination training regime" with an endurance programme on forty patients with chronic low back pain. Significant improvements in pain, mobility and disability scores were found in patients attending both programmes but no short- or long-term differences in these measures were found between the different rehabilitation regimes. The results of this study are difficult to assess because of high drop-out rates and the use of unvalidated endpoint measures.

The aim of this experimental study was to assess the effect of an established AS in-patient programme, previously shown to improve function and other endpoint measures (Band et. al. 1997), on spinal position sense in patients with mild AS. Due to time constraints, this study was run concurrently with the preceeding comparative study (Chapter 5) and was therefore initiated at a time when the results of this latter study were unknown. Ethical permission for this study was obtained from the Wiltshire and Bath Health Authority.

6.2 METHODS

6.2.1 Subjects

AS patients were recruited from in-patients attending an intensive two-week physiotherapy programme at a specialist rheumatology centre, the Royal National Hospital for Rheumatic Diseases, Bath, UK. At this centre, patients are allocated to "slow," "slow moderate," "fast moderate," and "fast" courses on the basis of the previously recorded metrology index (BASMI). Occasionally, other criteria such as age or concomitant disease may also influence the allocation of a patient to a particular group. The criterion for a "fast" course is a mean BASMI of less than 3 and this was the group from which most of the subjects for this study were recruited over a three year period. "Fast" courses are run approximately five

times a year. In the last year of data collection, the general increase in demand for in-patient rehabilitation, resulted in some "fast" course patients attending "fast moderate" courses. AS patients were therefore also recruited from two "fast moderate" groups during this period.

The reliability of postural measurements was assessed in thirteen additional patients (mean age 34 years) who fulfilled the study entry criteria but who were not receiving the in-patient programme. These patients were assessed on two seperate occasions two weeks apart.

Inclusion and exclusion criteria for this study were identical to those used in the previous comparative study involving AS patients (Chapter 5). Physiotherapy records of patients about to attend an in-patient course were examined in advance to ascertain those patients most likely to meet the study criteria. Those patients who, on the basis of these previous records, appeared to meet the study criteria, were given an information sheet (Appendix 2) explaining the requirements of the study. Five of these patients, did not meet the study criteria on reassessment. One had severe hip pain, the remaining four had a BASMI greater than 3 on one of the five components of the index. One of the patients who fulfilled the study criteria declined to take part because he felt that this might adversely affect his performance during the course. Twenty-five patients met the study criteria and gave informed consent to take part in the trial. One of these patients dropped out of the study because his pain was exacerbated following the pre-course assessment of spinal position sense. A further patient dropped out because a change in his domestic arrangements meant that he could not remain for assessment at the end of the course. Table 30 describes the remaining 23 AS patients who took part in this study.

6.2.2 Experimental protocol

Patients completed questionnaires to assess disease activity (BASDAI), and functional (BASFI) and global (BASG-1) indices of disease prior to measurement of position sense at the beginning and end of the course (Appendix 1). On each occasion, the metrology index (BASMI) was scored by one of three physiotherapists specialising in AS. Position sense testing was carried out prior to commencement, and immediately on completion, of the in-

patient programme. Patients were measured at least three hours after rising and at the same time of day (+/- one hour) at the start and finish of the course.

Measurements of spinal posture were taken from sensors sited at T1, T7, L1 and S2. At the beginning of each measurement session, patients stood without a blindfold and with their arms by their sides. To assess posture under naturalistic conditions, they were not asked to adopt any particular posture but were requested to "please stand still while I calibrate/recalibrate the machine." During this time, Fastrak recordings were taken over a two second time period and the average angle at each sensor location (between the Fastrak sensor and source) was determined.

	AS PATIENTS
Age (years) : **Mean** **Range**	 34 21-50
Height (m.): **Mean** **Range**	 174.58 156.5-194.5
Weight (kgs.): **Mean** **Range**	 77.23 52.1-109.4
Years since start of AS: **Mean** **Range**	 12.52 1-30
Years since diagnosis AS: **Mean** **Range**	 7.35 0-19
Male/Female	15M/8F
Right/left handed	22 R/ 1 L

TABLE 30 - Description of patients in in-patient study

Thoracic curvature was obtained by subtracting the angular reading at L1 from that at T1. Similarly, lumbar curvature was obtained by subtracting the measurement at S2 from that at L1 (Adams and Dolan, 1986). Assessment of pelvic tilt was obtained from S2 measurements. For lumbar and thoracic curvature, positive measurements denote a kyphosis; negative measurements a lordosis. Positive values for sacral tilt indicate an increase, and negative values a decrease, in sagittal pelvic tilt.

The protocol for the measurement of spinal position sense was as described previously in Chapter 5. Records of the distance between heels and big toes were used to replicate the stance adopted on the two test occasions. Records of the height of the source and its' distance from the patient were also used to ensure the same placement on both test occasions. Patients were required to reproduce upright and flexed spinal positions in the sagittal and coronal planes. They were asked to report any pain on a 0-10 analogue scale where 0 represented "no pain" and 10 "the worst pain imaginable." Data was recorded and stored on computer and analysed retrospectively at the end of the study.

Patients received the standard treatment package for AS in-patients, delivered by specialists who were employees at the centre. Exercises were undertaken for approximately six hours a day during the two weeks of the course, including the intervening weekend. The regime incorporated mobilising and strengthening exercises to all regions of the spine both on dry land and in the hydrotherapy pool. Some of these exercises, such as those using large gymnastic balls, demanded co-ordination of spinal movement (Appendix 5). In addition to exercise, there was an educational component to the course which included advice on posture, chronic pain management, and other aspects of the disease. None of the patients received a change in medication or invasive procedures such as injection into joints during the period of admission to hospital.

6.2.3 Statistical analysis

The reliability of postural measurements was analysed using repeated measures analysis of variance (ANOVA) and the intra-class correlation coefficient (*R*). The standard error of measurement (SEM - Appendix 3) was also calculated to determine the confidence limits of measurements of spinal curvature.

Differences in ankylosing spondylitis indices, thoracic and lumbar curvature and pelvic tilt, between the start and finish of the in-patient programme were assessed using matched pair t-tests. Pre- and post-course measurements of position sense were also analysed using this test. Statistical tests were two-tailed and a significance level of 5% was adopted.

6.3 RESULTS

6.3.1 Reliability of postural measurements

Results show that there are no significant differences in thoracic or lumbar curvature and sacral tilt between day 1 and day 2 (Table 31). Intra-class correlation coefficients (ICC) are good and range from *R* 0.88-0.91. The standard error of measurement for thoracic and lumbar curvature and sacral tilt ranges from 2.24 to 4.37 degrees (Table 31). These results suggest that measurements of spinal curvature have good relative reliability (p. 101) but rather low precision, especially for measurements of thoracic curvature, in relation to that of known angles obtained using the Fastrak (Chapter 2, pp. 93, 95).

	THORACIC KHYPHOSIS (degrees)		LUMBAR LORDOSIS (degrees)		SACRAL TILT (degrees)	
	DAY 1	DAY 2	DAY 1	DAY 2	DAY 1	DAY 2
Mean	49.55	49.26	-41.90	-40.44	16.35	15.62
St. Dev.	13.41	16.22	10.50	10.71	6.77	7.02
Range	28.8 to 73.8	33.2 to 86.7	-27.3 to -57.1	-25.6 to -63.5	5.3 to 29.1	3.4 to 29.5
ANOVA (p)	0.92		0.48		0.68	
ICC (*R*)	0.91		0.88		0.89	
SEM	4.37		3.61		2.24	

TABLE 31 - Day-to-day reliability of postural measurements in AS patients (n=13)
(Negative values indicate lumbar lordosis)

6.3.2 Pre - and post-course spinal position sense, posture and other endpoint measurements

There was a significant decrease in disease activity (BASDAI) and improvement in functional ability (BASFI) between the start and the finish of the in-patient programme. The global index (BASG-1) was also significantly reduced denoting an overall improvement in patients' perception of well-being (Table 32). There were significant increases in height and in range of movement in all components of the metrology index (Table 33). This was reflected in a significant decrease in the overall metrology index (BASMI) from 1.17 to 0.33 (Table 32).

	METROLOGY INDEX (BASMI)		DISEASE ACTIVITY INDEX (BASDAI)		FUNCTIONAL INDEX (BASFI)		GLOBAL INDEX (BASG-1)	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
MEAN	1.17	0.33	3.84	2.80	2.62	1.74	3.87	2.54
SD	0.60	0.29	2.81	1.41	1.91	1.31	2.24	1.42
t-test (p)	<0.00001*		0.0056*		0.00042*		0.0168*	
* Denotes statistical significance. Results are quoted to two decimal places. Reduction in scores indicates improvement. Pre = beginning of the in-patient programme. Post = end of the in-patient programme								

TABLE 32 - Pre-and post-course scores - metrology, disease activity, functional and global indices

	METROLOGY INDEX (BASMI)							
	TRAGUS-TO-WALL (cm)		MODIFIED SCHOBER (cm)		R. SIDE FLEXION (cm)		L. SIDE FLEXION (cm)	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Mean	10.80	9.84	6.98	7.64	18.29	24.30	18.68	24.11
St.Dev.	1.12	0.74	7.10	1.41	5.30	4.69	5.71	4.42
t-test (p)	< 0.001		<0.001		<0.001		<0.001	
	METROLOGY INDEX (BASMI)							
	CERVICAL ROTATION (R) (deg.)		CERVICAL ROTATION (L) (deg.)		INTER-MALLEOLAR DISTANCE (cm)		HEIGHT (cm)	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Mean	81.22	89.83	80.65	90.26	112.59	124.50	174.58	175.05
St.Dev.	7.10	4.29	9.78	5.48	11.82	10.54	9.84	9.57
t-test (p)	< 0.001		<0.001		< 0.001		<0.001	
* Denotes statistical significance. Results are quoted to two decimal places. **Pre** = beginning of the in-patient programme, **Post** = end of the in-patient programme								

TABLE 33 - Pre-and post-course metrology scores (BASMI) and height measurements (cm)

There were no significant changes in thoracic and lumbar curvature or sacral tilt following the course (Table 34) indicating that posture was little affected by the in-patient programme.

	THORACIC KHYPHOSIS (degrees)		LUMBAR LORDOSIS (degrees)		SACRAL TILT (degrees)	
	PRE	**POST**	**PRE**	**POST**	**PRE**	**POST**
Mean	43.05	42.27	-42.67	-42.53	14.71	15.41
St. Dev.	43.05	42.27	8.95	9.72	7.55	7.05
Range	15.5 to 63.8	21.7to 67.0	-26.2 to -55.6	-26.2 to -63.7	1.7 to 28.6	4.9 to 29.5
t-test (p)	0.84		0.94		0.74	

TABLE 34 - Pre-and post-course Fastrak measurements of thoracic and lumbar curvature and sacral tilt

No statistically significant differences in spinal position sense were observed between the start and finish of the in-patient programme (Figs. 19a-19c and Table 35). There was one outlying subject on the basis of the previously stated criteria (p. 117). This subject had outlying values in the sagittal and right coronal planes. However, differences between pre- and post-course position sense remained insignificant ($p > 0.17$) when this subject was removed from the sample.

Only two patients reported discomfort during testing and in both cases this was felt in one "halfway" position in coronal flexion. Discomfort was rated as 3/10 and 4/10 on a pain analogue scale by each patient respectively.

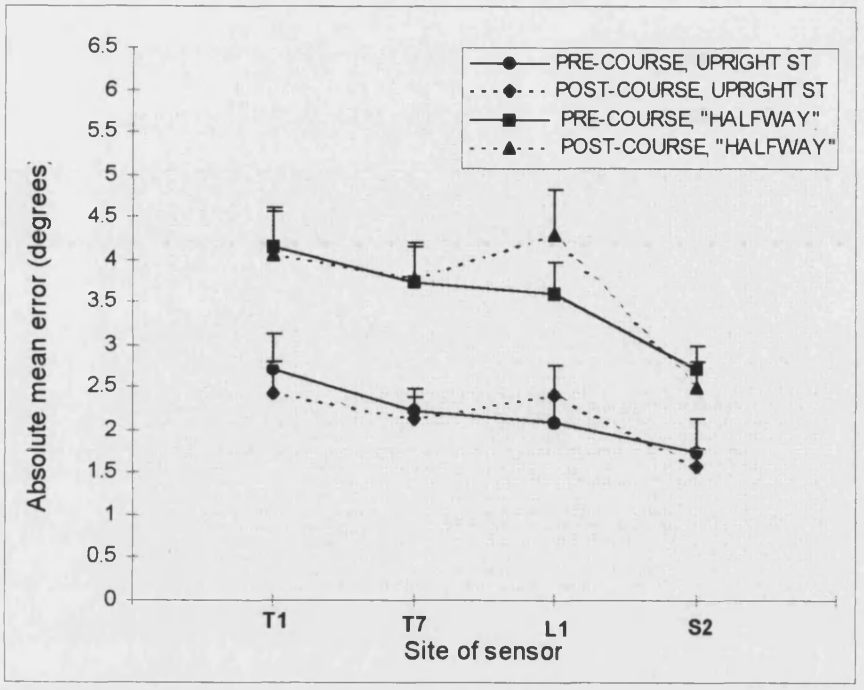


FIG. 19A - Pre- and post-course mean repositioning error at positions in the *sagittal plane* in AS patients

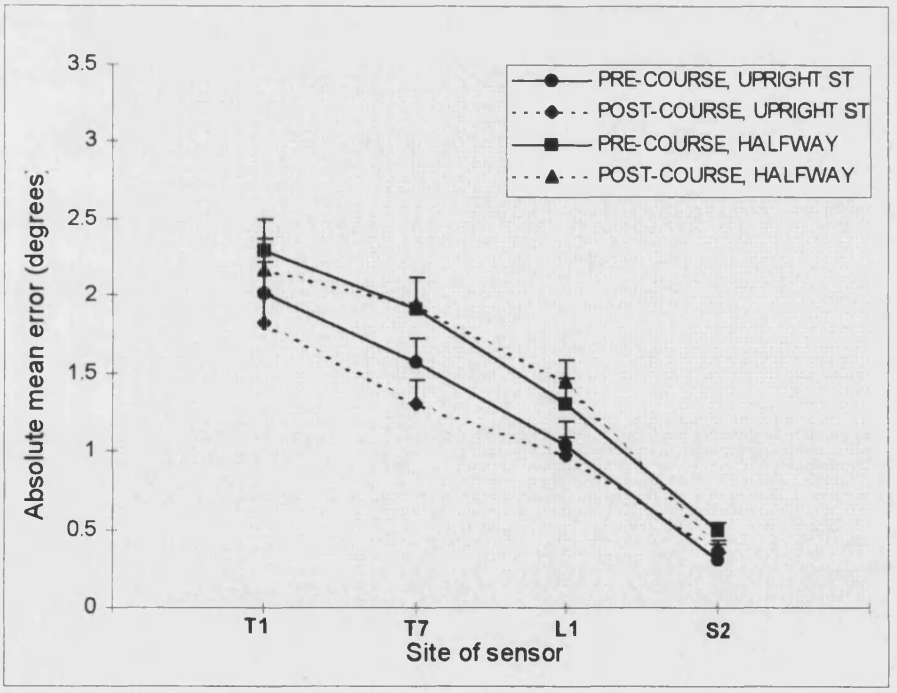


FIG. 19B - Pre- and post-course mean repositioning error at positions in the *right coronal plane* in AS patients

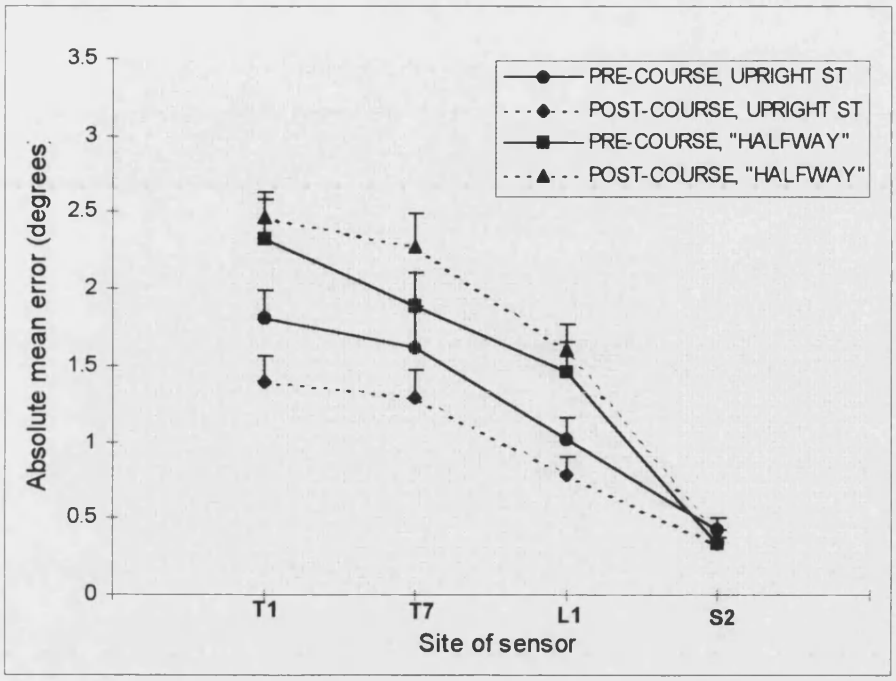


FIG. 19C - Pre- and post-course mean repositioning error at positions in the *left coronal plane* in AS patients

	UPRIGHT STANDING POSITIONS						"HALFWAY" POSITIONS					
Location of Sensor	**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**		**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**	
	PRE	PST	PRE	PST	PRE	PST	PRE	PST	PRE	PST	PRE	PST
T1												
Mean	2.71	2.44	2.02	1.82	1.81	1.40	4.15	4.06	2.29	2.17	2.32	2.47
St. Dev.	2.09	1.77	0.98	0.89	0.87	0.79	2.13	2.76	1.04	0.99	1.29	0.84
t-test (p)	0.57		0.37		0.07		0.90		0.66		0.65	
T7												
Mean	2.22	2.13	1.57	1.30	1.62	1.29	3.74	3.78	1.92	1.94	1.89	2.27
St. Dev	1.32	1.31	0.76	0.81	1.28	0.87	2.03	2.04	0.98	0.86	1.08	1.07
t-test (p)	0.79		0.24		0.09		0.94		0.94		0.15	
L1												
Mean	2.08	2.42	1.04	0.98	1.02	0.79	3.60	4.30	1.30	1.44	1.46	1.60
St. Dev	1.46	1.73	0.71	0.53	0.68	0.61	1.87	2.61	0.85	0.67	0.91	0.82
t-test (p)	0.42		0.74		0.25		0.28		0.49		0.54	
S2												
Mean	1.75	1.57	0.31	0.37	0.43	0.33	2.71	2.51	0.49	0.38	0.33	0.39
St. Dev	1.90	1.03	0.22	0.15	0.32	0.19	1.36	1.47	0.32	0.22	0.19	0.22
t-test (p)	0.48		0.32		0.10		0.59		0.056		0.29	

Results are the absolute repositioning errors in degrees quoted to two decimal places. Means and standard deviations are derived from the averaged results of the three trials in each position on each day. PRE = Pre-course, PST = Post-course.

TABLE 35 - Pre-and post-course absolute repositioning error in AS subjects

6.4 DISCUSSION

6.4.1 Reliability of postural measurements

6.4.1.1 Clinical measurements of posture

There is currently no standardised approach to the measurement of posture. Criteria for "ideal" normal posture were traditionally based on the concept of optimal alignment of key bony landmarks (Kendall et. al. 1952). Clinically, posture has been assessed by rating scales (Franklyn 1986), hand-held instruments such as plumb lines, inclinometers and flexicurves (Burdett et. al. 1986, Tillotson and Burton 1991), and horizontal linear measurement from a vertical reference point (Kraag et. al. 1990, Russell et. al. 1993b). Other appoaches to postural assessment include measurements obtained from x-rays (During et. al. 1985) or from electromagnetic tracking devices which can be attached to the skin (Dolan and Adams, 1993). However, in AS, height and tragus-to-wall or occiput-to-wall measurements are common postural endpoint assessments (Kraag et. al. 1990, Russell et. al. 1993).

In a prospective, longitudinal study of fifty-two AS patients, Roberts et. al. (1989), report significant changes in height both in response to a short intensive physiotherapy programme and a five-year time interval. The authors conclude that height is a sensitive anthropometric measurement in AS. The mean change in height over the five-year period was 1.1 cm and measurements were carried out by one physiotherapist. Clinically, an increase in height following physiotherapy is interpreted as indicating an improvement in spinal posture. Conversely, loss of height may be construed as deterioration of posture associated with disease progression over time. Measurements of overall height, however, have been shown to vary by about 1.9 cm over the course of a single day in healthy subjects (De Pukey 1935, Botsford et. al. 1994). Height measurements are therefore highly dependent on the time of day and, more specifically, on the recent loading history of the disc in the few hours prior to taking the height measurements. They are therefore unlikely to be a sensitive indicator of spinal posture in AS patients.

Tragus-to-wall measurement, which involves measurement of the horizontal distance from the tragus of the ear to a wall against which the person stands, has been shown to be accurate and reliable (Tomlinson et. al. 1986, Stokes et. al. 1988, Pile et. al. 1991, Jenkinson et. al. 1994). Empirically, tragus-to-wall measurement would appear to reflect

posture of the cervical and thoracic spine. A recent study of head and shoulder posture in 160 asymptomatic adults (Raine and Twomey 1997), however, found no association between forward head positioning and cervical or thoracic curvature in healthy subjects. The strength of any association between these in AS patients has yet to be determined. Longitudinal changes in tragus-to-wall measurement have been reported both in response to short periods of intensive physiotherapy (Pearcy et. al. 1985, Tomlinson et. al. 1986, Viitanen et. al. 1992) and over longer periods of time (Carette et. al. 1983). In the latter prospective study, fifty-one AS patients were followed up over a period of thirty-three years. There was an increase in tragus-to-wall measurement over time (Carette et. al. 1983). Tragus-to-wall measurement is one of several parameters that have been incorporated into the multi-dimensional metrology measure, the Bath AS Metrology Index (BASMI) that was used in the present study. This index been shown to be sensitive to change across a broad spectrum of disease in response to a short intensive physiotherapy programme (Jenkinson et. al. 1994).

6.4.1.2 Reliability of Fastrak measurements of posture

In addition to clinical measurements of height and tragus-to-wall distance, angular measurements obtained from Fastrak sensors were taken to assess spinal curvature. Intraclass correlation co-efficients (ICC) and analysis of variance (ANOVA) indicated good day-to-day relative reliability of postural measurements obtained from sensors placed at T1, T7, L1 and S2. However, the standard error of measurement (SEM) placed fairly large 95% confidence limits around individual measurements particularly those of thoracic curvature (SEM 4.37, 95% confidence limit +/- 8.74 degrees). This may, in part, reflect the calculation of spinal curvature from angular measurements taken at two sites. In addition, measurements of thoracic curvature may be subject to some variation in subjects who have a particularly protuberant spinous process at T1 which may cause slight tilting of the sensor at this site. Measurement of sacral tilt, taken from one site at S2, gave the least wide 95% confidence limits (+/- 4.48).

Bullock-Saxton (1993) assessed thoracic and lumbar curvature and pelvic tilt in a group of healthy adults. As in the current study they found no significant differences in day-to-day measurements when assessed by analysis of variance. No other measures (eg. SEM) of

absolute reliability or measures of relative (eg. ICC) reliability are, however, reported in this study. Adams et. al. (1986) and Dolan and Adams (1993), similarly, report good day-to-day and within-day reproducibility of lumbar curvature measurements in upright standing in healthy subjects. Repeated measurements of lumbar curvature were assessed in one and two subjects respectively and reproducibility is reported on the basis of a within subject standard deviation of ± 2.5 degrees. In the second study, measurements were obtained using a similar electro-magnetic analysis system (the Isotrak), and a similar method of fixation to that used in this current study.

6.4.2 Lumbar posture in AS patients with early disease

Measurements of lumbar curvature in the AS patients in this study are similar to those reported for healthy subjects using a similar electromagnetic measuring device (Adams et. al. 1999). These authors report a mean lumbar curvature of 30.4 degrees in a group of 403 healthy adults. Measurements of lumbar curvature in the current study suggest an overall greater lordotic posture in AS patients with mild disease. However, these values were well within the normal range of movement indicated by this earlier study (Adams et. al. 1999). This group of patients with early AS therefore showed no evidence of any flattening of the lumbar lordosis which is sometimes reported to be the first sign of postural change in AS (Simmons et. al. 1991, Becker-Cappeller 1994, Viitanen and Suni 1995).

6.4.3 The effect of the in-patient programme on spinal position sense and other endpoint measurements

Improvements in metrology (BASMI), disease activity (BASDAI), function (BASFI) and global well being (BASG-1) following the two-week in-patient programme accord with those of a recent large retrospective study of 236 AS patients who attended the same course (Band et. al. 1997). A percentage of patients in this earlier study reported a deterioration in indices of disease activity (BASDAI - 32%), function (BASFI - 14%), and global well-being (BASG-1 - 27%). These figures equate with the current findings which indicated deterioration in these indices in 26%, 13% and 30% of patients respectively. Although subjects in the present study were a select group of "fast" course patients, the profile of post-course improvement would appear to reflect that of the previous larger study of patients across a broader spectrum of disease. Current results suggest that even patients

with mild disease may experience a significant improvement in metrology and function following an intensive in-patient programme.

There were no significant differences in lumbar and thoracic curvature and pelvic tilt between the start and finish of the in-patient programme. Improvements in function (BASFI), disease activity (BASDAI), metrology (BASMI) and global well-being over the preceding week (BASG-1) do not, therefore, appear to be associated with changes in spinal posture. While overall height and tragus-to-wall measurement may be interpreted as clinical measurements which reflect posture, changes in both these parameters, although significant, were only small. The relationship between these measurements and spinal curvature has yet to be established.

Improvements in metrology, function and other outcome measures also do not appear to be accompanied by significant changes in spinal position sense. Spinal position sense in AS patients, both before and after an intensive therapy programme, is similar to that reported for both patients and healthy subjects in the previous comparative study (Chapter 5). The potential for proprioception retraining may only exist in subjects with overt proprioceptive deficits (Hurley 1997). While several studies suggest that movement sense (Barrack et. al. 1984, Lephart et. al. 1996) or postural sway (Hoffman and Payne 1995, Leanderson et. al. 1996) may be improved by training in healthy (non-deficit) subjects, there is no corresponding evidence of improvement in position sense. Clinical studies have also yet to provide substantive evidence of proprioceptive retraining potential in patients.

A further consideration is that details of the mechanisms underlying the retraining of proprioception are unknown. The variety of exercises in the in-patient programme, and their overall low specificity for proprioceptive training, may have mitigated against any potential effect based on highly specific neurological processes. Only two examples of training programmes which purport to target spinal proprioception are described in the literature (Norris et. al. 1995, Johannsen et. al. 1995). As in peripheral joints, these spinal programmes incorporate dynamic co-ordination and balancing exercises of increasing complexity (Johannsen et. al. 1995, Hoffman and Payne 1995). No studies have been reported which assess the effect of these or equivalent programmes on spinal proprioception. However, peripheral studies which report improvements in proprioception

following training, incorporate similar dynamic balance and co-ordination exercises (Freeman et. al. 1965, Beard et. al. 1994). Less specific exercises, such as those in the programme described in the current study, may not be successful in enhancing proprioception. Position sense in the anterior cruciate deficient knee, for example, does not appear to be improved by a general exercise programme (Carter et. al. 1997).

6.5 SUMMARY

There were no significant differences in spinal position sense in a cohort of AS patients with mild disease following an intensive in-patient therapy programme. Changes in metrology, function, disease activity and global indices of disease, however, indicated an improvement in outcome and were similar to improvements reported in a previous, larger study of the same AS in-patient programme. Increasing mobility and function through intensive training did not appear to affect spinal position sense in AS patients. This may reflect previous findings on the integrity of spinal proprioception in patients with mild disease or the low specificity of exercises in the programme in targeting proprioceptive training.

CHAPTER 7

A LONGITUDINAL STUDY OF SPINAL POSTION SENSE IN PATIENTS WITH ANKYLOSING SPONDYLITIS

7.1 INTRODUCTION

In Chapter 5, a technique developed for measuring spinal position sense was found to produce reliable results in patients at several sensor locations. In addition, no clinically significant differences in spinal position sense were found between patients with mild disease and healthy controls. In Chapter 6, spinal position sense was assessed in patients before and after an in-patient programme which incorporated exercise and is associated with improvement in mobility and function. Although significant post-course improvements were found in metrology, function, and disease activity, no changes were found in spinal position sense. This result may reflect the lack of specificity of the exercises in the in-patient programme for improving proprioception. The exercises were primarily aimed at strengthening and mobilising the spine rather than improving proprioception. Alternatively, AS patients with mild disease have previously been shown to have intact position sense (Chapters 5 and 6) and there is no substantive evidence that proprioception improves in the absence of any impairment (pp. 36-39).

AS tends to be a progressive disease and one which is associated with deterioration in mobility and posture over time (Moll 1986, Carette et. al. 1983, Becker-Cappeller 1994, Gran and Skomsvoll 1997). This deterioration is attributed to progression of pathological changes in spinal and para-spinal structures (Vernon-Roberts 1998). These structures include ligamentous, tendinous and annular entheses, facet joint capsules, ligaments and paraspinal muscles all of which have been shown to contain populations of afferents which subserve proprioception (Amonoo-Kuofi 1982, Nitz and Peck 1986, Ford et. al. 1988, Yamashita et. al. 1990, 1993, McLain 1994). Increasing involvement of these sites in response to disease progression in ankylosing spondylitis may therefore result in impairment of spinal proprioception. Any such deficit in spinal proprioception may be related to the deterioration in posture associated with the disease and for which there is no established cause (Chapter 1, 52-54).

The aim of this study is to assess the effect of a 12-18 month time interval on disease progression, spinal position sense and posture in AS patients with mild disease. Disease progression will be monitored, as described in the previous study, using validated indices of disease activity (BASDAI), function (BASFI), spinal metrology (BASMI) and global well-being (BASG-1). Postural measurements will be taken to determine whether any changes in posture over time are associated with changes in spinal position sense. Ethical permission for this study was obtained from the Wiltshire and Bath Health Authority.

7.2 METHODS

7.2.1 AS patients

Patients who took part in the comparative study (Chapter 5) were recalled for spinal position sense testing following a minimum time period of one year (mean time interval 13.66 months, range 12-17 months). For logistical reasons, only those patients who lived within two hours travelling time of the testing centre were requested to attend for reassessment. Travel expenses were paid from project funds. Six of the initial local patients were unable to attend for reassessment. Three of these were currently experiencing a severe flare-up of disease and one had transport difficulties. One patient was unable to attend due to pressure of work and another patient had moved out of the area. The remaining sample size was 27. The same protocol was used as for the comparative study in chapter 5. Patients were screened by medical questionnaire and checked for the same exclusion criteria. No patients were receiving physiotherapy or comparable treatment. The minimum period which had lapsed since attendance at an in-patient rehabilitation programme was nine months.

7.2.2 Protocol

Disease activity (BASDAI), functional (BASFI) and global (BASG-1) self-assessments were completed by each patient before the start of the position sense testing protocol. Similarly, the metrology index (BASMI) was assessed by one of three specialist physiotherapists without sight of previous metrology scores. Patients were also asked to describe in one sentence how their AS had been since the first assessment session including

any "flare-ups" in the condition. Table 36 describes the subjects who took part in this longitudinal study.

Measurements of spinal posture were taken from sensors sited at T1, T7, L1 and S2 using the technique previously described (p.190). The protocol for spinal position sense assessment was as described in Chapter 5. Records of the distance between big toes and mid heels were used to replicate the stance adopted at the first assessment session. Similarly, records of the position of the source on the wooden stand were used to ensure the same placement at the first and follow-up session. Measurements were made at the same time of day (+/- one hour) on both occasions and at least three hours after rising. Subjects were asked to reproduce upright and flexed positions in the coronal and sagittal planes and to report any pain during the procedure. Pain was scored on a 0-10 analogue scale where 0 represents "no pain" and 10 "the worst pain imaginable." Graphic representations of the positions adopted during position sense tests were stored on floppy disc and analysed retrospectively.

	AS PATIENTS
Age (years) : **Mean** **Range**	 34.26 23-50
Height (m.): **Mean** **Range**	 1.75 1.55-1.91
Weight (kgs.): **Mean** **Range**	 75.52 55-102
Years since start of AS: **Mean** **Range**	 12.22 1-24
Years since diagnosis AS: **Mean** **Range**	 6.55 1-19
Male/Female	19M/8F
Right/left handed	26R/1L

TABLE 36 - Description of patients in longitudinal study

7.2.3 Statistical analysis

Ankylosing spondylitis indices and measures of spinal curvature on the two occasions were compared using matched pair t-tests. Absolute mean repositioning errors at the first and follow-up assessment were also compared using this test. Associations between changes in spinal curvature at different regions of the spine and changes in position sense were assessed using the Pearson Product Moment Correlation Coefficient (*r*). Tests were two-tailed and a significance level of 5% was adopted.

7.3 RESULTS

7.3.1 Posture and other endpoint measures at first and follow-up assessments

Table 37 shows mean changes in all the AS indices between the first and follow-up measurement sessions. There was a significant increase in the disease activity index (BASDAI, p = 0.009) and the metrology index (BASMI, p = 0.006) indicative of more severe disease. This is reinforced by the subjective comments of patients, 62% of whom reported flare-ups and a general worsening of their condition over the time period (Table 38). Analysis of individual components of the metrology index (BASMI), showed a significant decrease in left and right side flexion (p = 0.004, p = 0.02 respectively) between first and follow-up measurements (Table 39).

	METROLOGY (BASMI)	DISEASE ACTIVITY (BASDAI)	FUNCTION (BASFI)	GLOBAL INDEX (BASG-1)
MEAN	+0.33	+0.70	+0.44	+0.39
SD	0.58	1.31	1.27	1.77
RANGE	-0.6 to 2.3	-2.49 to 3.57	-1.12 to 4.85	-5.05 to 3.75
FIRST V FOLLOW-UP Paired t-test (*p*)	0.006*	0.009*	0.08	0.27
Postive values (+) denote increase in severity. * denotes statistical significance.				

TABLE 37 - Changes in ankylosing spondylitis indices between first and follow-up assessments

Q: Please describe in one sentence how you have been since I last saw you

AS01 (F)	Pain and stiffness have increased since I had my baby. (6 months previously)
AS02 (F)	Like a see-saw. My chest and right shoulder are more painful.
AS03 (M)	Generally fine. Much the same.
AS04 (M)	Uncomfortable. Pain in shoulder, neck and left hip.
AS05 (F)	Same, but a few more bad clusters of days.
AS06 (F)	Patchy. Problems with shoulder, hips and neck. Local flare-ups.
AS07 (M)	Generally very well. Occasional flare-ups for the odd day or two.
AS08 (M)	Fine. Improved. Occasionally wakes me at night.
AS09 (F)	Basically not too bad. Nothing new has flared up. Lots of fatigue.
AS10 (F)	Flare up last May. Six days of sciatic pain in right leg.
AS11 (M)	Steady. Occasional plantar fasciitis.
AS12 (M)	Good. My last flare up was 2 years ago - very severe.
AS13 (M)	Worse. Pain in ribs and chest.
AS14 (M)	Pretty good. No real prolonged flare-ups. My flare-ups last less than a week. The last one was in 1995.
AS15 (F)	Pain and stiffness have increased. Not as bad as when I was diagnosed though.
AS16 (M)	Plantar fasciitis both feet. Getting worse. Difficult to walk sometimes. OK today.
AS17 (M)	Flare-up for eight days last January. More tired over the last year. More stiff in the mornings.
AS18 (M)	Pretty good - apart from my neck.
AS19 (M)	On the whole quite well. More fatigue now.
AS20 (M)	Good. No flare-ups. Occasional left sided rib pain.
AS21 (F)	Quite a lot of flare-ups. Especially my chest. Several bouts of hip bursitis.
AS22 (M)	Pretty good. More tired. I've got a new fitness regime.
AS23 (M)	More pain and stiffness. I've lost a lot of movement. Changed my job - I'm sitting a lot now.
AS24 (M)	Fine. I had a flare-up in my right hip for a week - a month ago.
AS25 (M)	A few flare-ups in my hips and sacro-iliacs. Pain wakes me up four nights a week.
AS26 (M)	(missing data)
AS27 (M)	Generally fine. Much the same. Had a flare-up in the summer for three days.

TABLE 38 - Subjective comments of AS patients on follow-up assessment

	COMPONENT OF METROLOGY INDEX (BASMI)					
	TRAGUS TO WALL (cm)	MODIFIED SCHOBER (cm)	RIGHT CORONAL FLEXION (cm)	LEFT CORONAL FLEXION (cm)	RIGHT CERVICAL ROTN. (degrees)	LEFT CERVICAL ROTN. (degrees)
MEAN	+0.33	-0.24	-1.69	-2.29	+0.48	+0.81
SD	1.34	1.09	3.54	3.83	9.53	5.92
RANGE	-2.9 to 3.9	-2.8 to 1.8	-9.4 to 7.3	-9.5 to 5.3	-27 to 20	-12 to 19
1st versus Follow-up assessment t-test (*p*)	0.21	0.27	0.02*	0.004*	0.79	0.48
	Positive (+) values indicate an increase in tragus-to-wall distance or an increase in range of movement. Negative (-) values indicate a decrease in tragus-to-wall distance or a decrease in range of movement. * denotes statistical significance.					

TABLE 39 - Changes in metrology in AS patients following a mean time interval of 13.66 months

Table 40 shows mean values for spinal curvature on the two test occasions. Measurements of spinal posture showed wide variation between individuals. The angle of pelvic tilt and lumbar curvature showed a significant negative correlation at both first and follow-up assessment (*r* -0.56, p = 0.002 and *r*-0.77, p <0.0001 respectively). Table 41 shows the mean changes in spinal curvature and height between first and follow-up measurements Change in lumbar curvature at follow-up was almost significant (p 0.0538) and was significantly correlated with change in sacral tilt at S2 (*r* 0.62, p 0.001). There was no significant correlation between changes in lumbar and thoracic curvature (*r* -0.33, p 0.09). Inspection of individual data on spinal curvature showed that eleven subjects had slight loss of the lumbar lordosis (range 0.3 to 8.8 degrees). Fifteen subjects had increased lumbar lordosis (range -1.6 to -23.4 degrees) and one remained the same.

	THORACIC CURVATURE (degrees)		LUMBAR CURVATURE (degrees)		SACRAL TILT (degrees)	
	FIRST	**FOLLOW-UP**	**FIRST**	**FOLLOW-UP**	**FIRST**	**FOLLOW-UP**
MEAN	+47.74	+44.97	-40.87	-44.01	+15.83	+17.06
SD	14.04	16.55	9.22	9.30	6.33	6.33
RANGE	16.7 to 73.8	18.6 to 75.2	-27.2 to -57.1	-29.1 to -63.2	5.1 to 29.1	9.0 to 30.2
	Negative values (-) indicate lordosis, positive values (+) indicate kyphosis				Positive values (+) indicate anterior tilt	

TABLE 40 - Spinal curvature in AS patients at first and follow-up measurements

	CHANGE IN SPINAL CURVATURE (degrees)			
	THORACIC CURVE (degrees)	LUMBAR CURVE (degrees)	SACRAL TILT (degrees)	HEIGHT CHANGE (cm)
MEAN	-2.77	-3.14	+1.23	-0.18
SD	11.22	8.09	4.51	0.86
RANGE	-33.1 to 26.8	-8.8 to 23.4	-7.0 to 12.7	-2.0 to 1.3
1st v. FU assessment t-test (*p*)	0.26	0.0538	0.17	0.28
	Thoracic and lumbar curves - negative values (-) indicate change in a lordotic direction. Sacral tilt - positive value (+) indicates change in an anterior direction			

TABLE 41 - Changes in spinal curvature in AS patients between first and follow-up measurements

7.3.2 Spinal position sense at first and follow-up assessments

There were no significant differences in spinal position sense following a mean time interval of 13.66 months (Table 42 and Figs.20A-20C). As in previous studies (Chapters 5 and 6), position sense tended to improve from cephalad to caudad and to be better in the coronal compared to the sagittal plane. Differences between first and follow-up measurements of repositioning error are statistically insignificant. The largest difference of 0.68 degrees is at L1 on return to upright standing from sagittal flexion.

	UPRIGHT STANDING POSITIONS						"HALFWAY" POSITIONS					
Location of Sensor	**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**		**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**	
	1st	**FU**	**1st**	**FU**	**1 st**	**FU**	**1 st**	**FU**	**1 st**	**FU**	**1 st**	**FU**
T1												
Mean	2.71	2.25	1.76	0.93	1.83	1.73	3.50	3.77	2.46	2.23	2.54	2.13
St. Dev.	1.49	1.48	1.19	0.96	1.02	1.02	2.09	1.75	1.68	1.60	1.69	1.34
t-test (p)	0.22		0.42		0.66		0.58		0.33		0.22	
T7												
Mean	1.71	2.13	1.55	1.55	1.66	1.60	3.27	3.38	2.19	2.09	1.74	1.81
St. Dev	0.70	1.29	0.66	1.16	0.98	0.90	1.68	1.49	1.22	1.25	1.16	1.18
t-test (p)	0.12		0.99		0.73		0.81		0.80		0.74	
L1												
Mean	1.51	2.19	1.13	0.96	1.09	1.07	3.48	3.29	1.32	1.26	1.40	1.34
St. Dev	1.13	1.74	0.73	0.68	0.68	0.55	1.48	1.31	0.89	0.87	0.70	0.65
t-test (p)	0.08		0.22		0.91		0.61		0.74		0.65	
S2												
Mean	1.47	1.53	0.31	0.33	0.44	0.38	2.72	2.18	0.40	0.38	0.42	0.42
St. Dev	0.92	0.80	0.18	0.24	0.27	0.31	1.26	1.20	0.27	0.25	0.26	0.39
t-test (p)	0.75		0.55		0.23		0.11		0.65		0.98	

Results are the absolute repositioning errors in degrees quoted to two decimal places. Means and standard deviations are derived from the averaged results of the three trials in each position on each day.

TABLE 42 - Spinal position sense - first (1st) and follow-up (FU) assessment in AS patients (n=27)

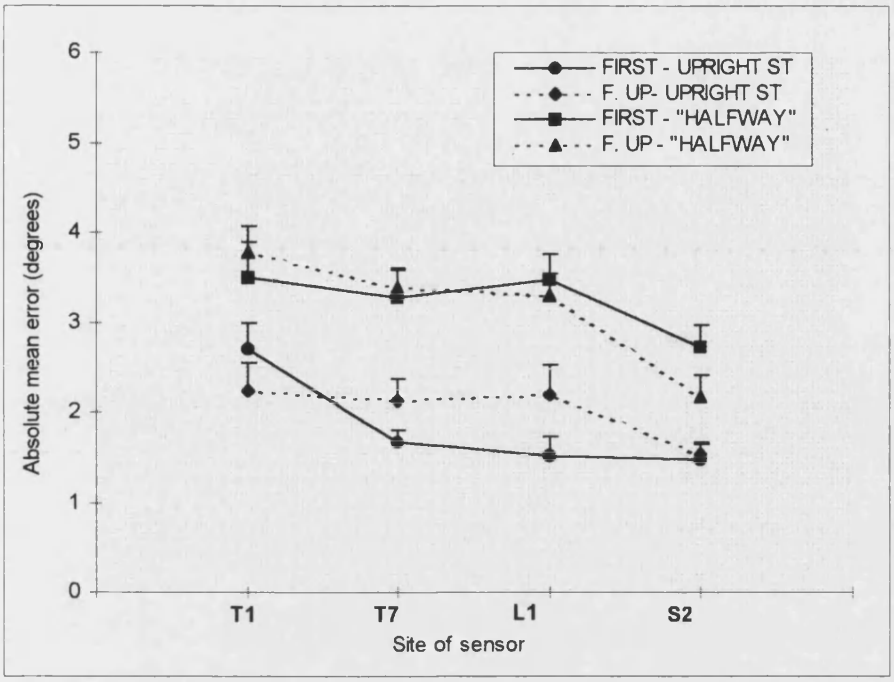


FIG. 20A - Repositioning errors in upright standing and "halfway" flexed positions in the sagittal plane. First v. follow-up assessment of AS patients

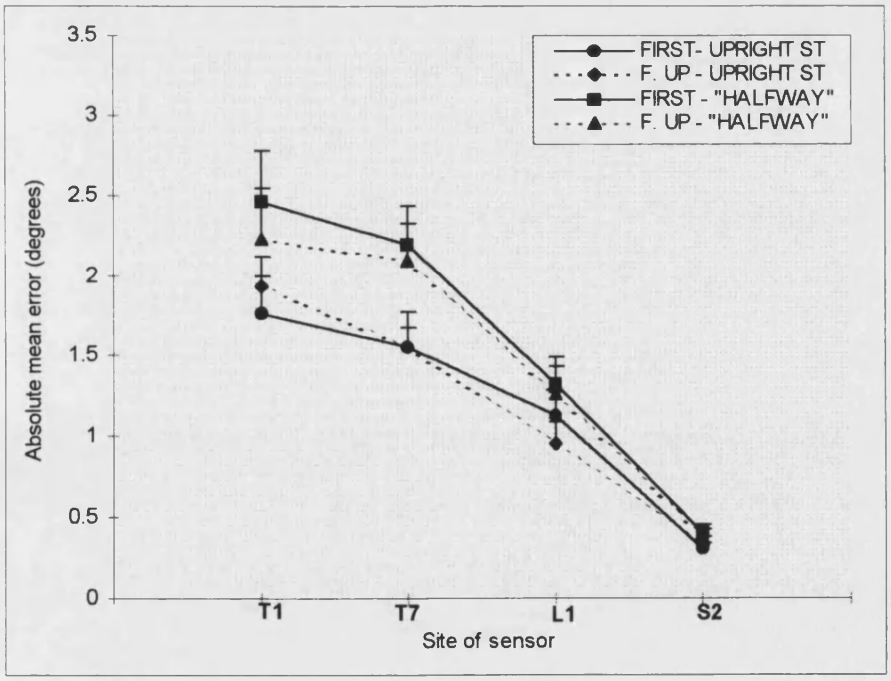


FIG. 20B - Repositioning errors in upright standing and "halfway" flexed positions in the right coronal plane. First v. follow-up assessment of AS patients

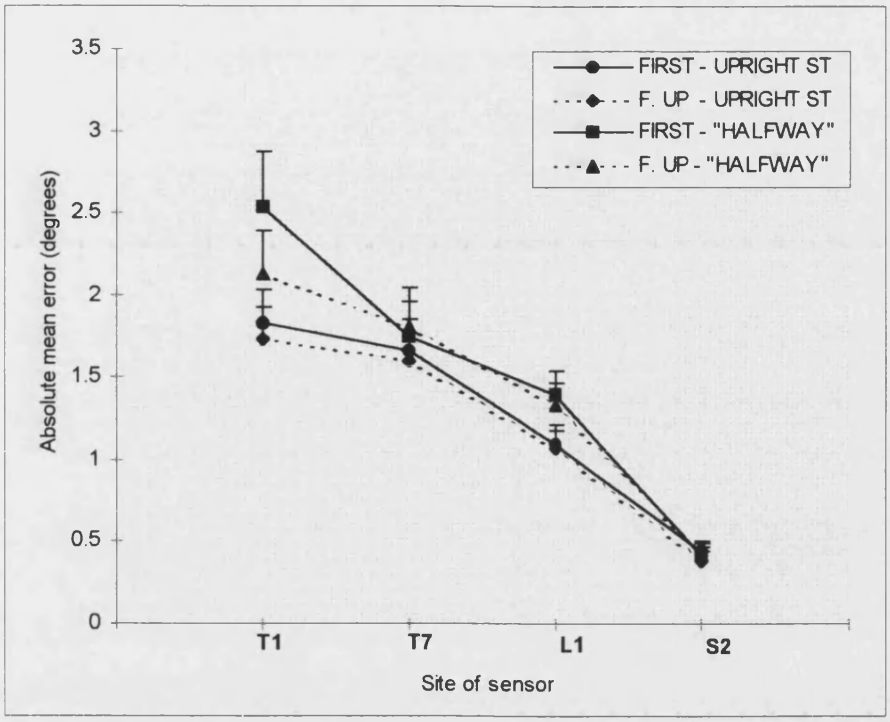


FIG. 20C - Repositioning errors in upright standing and "halfway" flexed positions in the left coronal plane. First v. follow-up assessment of AS patients

There was one outlying subject on the basis of the previously stated criteria (p. 117). This subject had outlying values at all sensor sites and in the sagittal and coronal planes on both days. There was no difference between first and follow-up measurements of spinal position sense ($p > 0.28$) when data was re-analysed with this subject removed from the sample.

Tables 43 and 44 show results with the group divided into patients diagnosed recently (≤5 years, n=14) or more than five years ago (n=13) respectively. There were no significant differences between initial and follow-up repositioning errors with the exception of upright standing at L1 on return from sagittal flexion (p 0.02) in patients diagnosed five or more years ago. Here the mean difference between measurements was 0.88 degrees.

	UPRIGHT STANDING POSITIONS						"HALFWAY" POSITIONS					
Location of Sensor	**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**		**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**	
	1st	**FU**	**1st**	**FU**	**1 st**	**FU**	**1 st**	**FU**	**1 st**	**FU**	**1 st**	**FU**
T1												
Mean	2.42	2.50	1.51	1.82	1.68	1.49	3.41	4.41	2.49	2.04	2.45	2.18
St. Dev.	1.03	1.54	0.94	0.73	0.77	0.98	2.14	1.79	1.79	1.49	1.34	1.20
t-test (p)	0.88		0.38		0.57		0.18		0.13		0.58	
T7												
Mean	1.59	2.13	1.50	1.47	1.41	1.26	3.05	3.95	2.31	2.18	1.57	1.87
St. Dev	0.65	1.38	0.70	1.37	0.90	0.74	1.43	1.55	1.29	1.32	0.99	0.92
t-test (p)	0.16		0.95		0.61		0.12		0.64		0.32	
L1												
Mean	1.93	2.41	0.93	0.72	0.93	0.79	3.34	3.82	1.53	1.19	1.41	1.24
St. Dev	1.36	2.22	0.46	0.36	0.46	0.49	1.29	1.16	0.97	0.71	0.79	0.52
t-test (p)	0.48		0.28		0.41		0.23		0.26		0.39	
S2												
Mean	1.28	1.22	0.27	0.34	0.35	0.29	2.28	2.19	0.45	0.36	0.38	0.46
St. Dev	0.83	0.65	0.13	0.23	0.24	0.19	0.90	1.34	0.25	0.17	0.17	0.47
t-test (p)	0.79		0.39		0.47		0.81		0.09		0.54	

Results are the absolute repositioning errors in degrees quoted to two decimal places. Means and standard deviations are derived from the averaged results of the three trials in each position on each day.

TABLE 43 - Spinal position sense - first (1st) and follow-up (FU) assessment in AS patients with recent (≤5 years) diagnosis (n=14)

	UPRIGHT STANDING POSITIONS						"HALFWAY" POSITIONS					
Location of Sensor	**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**		**Sagittal Flexion**		**Right Coronal Flexion**		**Left Coronal Flexion**	
	1st	**FU**	**1st**	**FU**	**1 st**	**FU**	**1 st**	**FU**	**1 st**	**FU**	**1 st**	**FU**
T1												
Mean	3.02	1.97	2.03	2.05	1.93	1.97	3.61	3.07	2.43	2.44	2.63	2.08
St. Dev.	1.85	1.43	1.40	1.19	1.02	0.94	2.11	1.07	1.63	1.74	1.74	1.52
t-test (p)	0.06		0.91		0.96		0.38		0.97		0.24	
T7												
Mean	1.84	2.13	1.62	1.64	1.25	1.38	3.49	2.76	2.06	2.00	1.93	1.75
St. Dev	0.76	1.24	0.63	0.92	0.85	0.45	1.94	1.20	1.18	1.23	1.33	1.44
t-test (p)	0.46		0.94		0.81		0.31		0.81		0.60	
L1												
Mean	1.06	1.94	1.35	1.22	1.25	1.38	3.64	2.73	1.10	1.34	1.39	1.45
St. Dev	0.61	1.04	0.91	0.85	0.85	0.45	1.71	1.26	0.77	1.04	0.62	0.78
t-test (p)	0.02*		0.54		0.52		0.16		0.22		0.74	
S2												
Mean	1.67	1.88	0.34	0.33	0.54	0.48	3.20	2.17	0.35	0.41	0.46	0.38
St. Dev	1.01	0.84	0.22	0.27	0.27	0.38	1.45	1.07	0.30	0.32	0.34	0.30
t-test (p)	0.57		0.81		0.29		0.08		0.52		0.49	

* denotes statistical significance. Results are the absolute repositioning errors in degrees quoted to two decimal places. Means and standard deviations are derived from the averaged results of the three trials in each position on each day.

TABLE 44 - Spinal position sense - first (1st) and follow-up (FU) assessment in AS patients with later (>5 years) diagnosis (n=13)

7.3.3 Association between spinal position sense and other endpoint measures

There were no significant associations between differences in spinal position sense and those in other endpoint measures (BASMI, BASDAI, BASFI) over the 12 to 18 month period.

There were no significant correlations between position sense measurements in the sagittal plane and thoracic curvature, lumbar curvature or pelvic tilt on either of the test occasions. There was also no significant correlation between changes in spinal position sense at L1 or S2 in upright standing from sagittal flexion and changes in antero-posterior lumbar curvature over time (r 0.32, p 0.10; r -0.35, p 0.07 respectively).

7.4 DISCUSSION

7.4.1 Longitudinal changes in indices of disease activity and progression

Although patients were selected on the basis of good metrology scores, there are indications of disease progression over the relatively short time span of 12-18 months. Metrology (BASMI) and disease activity (BASDAI) indices, which have been shown to be sensitive and reliable indicators of disease progression (Garrett et. al. 1994, Jenkinson et. al. 1994), were significantly increased. Despite the wide variation in time since disease onset, 67% of patients experienced a deterioration in metrology (BASMI) and 93% of patients an increase in disease activity (BASDAI) over the period of the study. The subjective comments of the majority of patients (Table 38) also suggest on-going disease activity over this time. In addition, coronal flexion, which occurs in the lower thoracic and lumbar spine, and is one of the earliest movements restricted in AS (Jenkinson et. al. 1994), was significantly reduced between first and follow-up assessments. The inter-rater reliability of measurements of coronal flexion, obtained using a technique similar to that of the current study, have been shown to be good (Jonsson et. al. 1995). These differences are therefore likely to represent real loss of coronal flexion over time.

Although there was a statistically significant increase in disease activity and reduction in mobility over the period of the study, this is not matched by a commensurate reduction in the functional index (BASFI). BASFI is, however, almost significantly reduced and may

not be as sensitive to disease progression as other indices due to inherent problems of functional assessment such as compensatory movement (Chapter 1, pp. 58-59). Similarly, the global index, BASG-1, may reflect a host of factors which influence patient perceptions of overall well-being in addition to those related to disease progression.

7.4.2 Longitudinal changes in posture in AS patients

There were no significant changes in Fastrak measurements of thoracic and lumbar curvature, or the angular position of S2 (ie. hip flexion) between first and follow-up measurements 12 to 18 months later. Changes in lumbar curvature are almost significant ($p < 0.0538$) and there is a small overall mean increase in lumbar lordosis of 3.14 degrees. This result should, however, be interpreted in the light of the relatively large 95% confidence interval of +/-7.22 degrees (twice the SEM) for measurements of lumbar curvature (Chapter 6, p. 192).

Inspection of raw data suggests that this near significant difference in lumbar curvature over time is attributable to a minority of subjects. One female and two males increased their lumbar lordosis by more than fifteen degrees. In one male patient the increase in lumbar lordosis was associated with an increase in anterior pelvic tilt but no comparable change in thoracic curvature. Examination of other endpoint measures did not reveal any outstanding features in this patient to which the large increase in lumbar lordosis might be attributed. In the female patient, the increase in lumbar lordosis was associated with a large increase in thoracic kyphosis and a marked reduction in hip abduction suggesting severe hip involvement. This patient had been pregnant six months previously. Pregnancy may exacerbate primary AS (Gran and Husby 1990) and may also have contributed to the increase in lordotic posture in this patient. None of the three patients had radiological changes in the hip joints on x-rays taken 2 to 6 years earlier. However, hip disease may have started in the period since the last x-ray and it may cause hip flexion contracture which can result in a compensatory increase in lumbar lordosis (p. 53).

AS patients in this study demonstrated the range and variability of measurements of lumbar curvature present in the normal population. In addition, there was no significant reduction in lumbar lordosis over time. However, flattening of the lumbar lordosis is generally

considered a common clinical feature of AS and one which may occur relatively early in the disease process (Khan 1998). Patients were selected on the basis of low BASMI scores and therefore had relatively good spinal mobility which is associated with less spinal deformity than patients with more advanced disease (Carette et. al. 1983). The potential for postural change over time would therefore appear to be greater in this group of relatively mobile patients than with less mobile patients with established deformity. The lack of significant postural changes over time, despite the significant increase in disease progression, may reflect the relatively short time interval (12-18 months) over which the current study was conducted. Swannell (1988) also found no significant changes in spinal shape in a study conducted over a slightly longer period of two years. AS has a long natural history and, in the majority of patients, postural changes may occur insidiously over protracted periods of time. While there were no overall significant changes in posture over the 12-18 month time interval, results suggest that a small minority of patients may experience large changes in posture over a relatively short period of time. The cause of these gross postural changes is unknown but hip joint involvement may be a factor in some patients.

7.4.3 Longitudinal changes in position sense in AS patients

Results showed that there were no significant differences in the ability to reposition the spine in flexed and upright positions following a mean time interval of 13.66 months. Spinal position sense in this cohort of patients was comparable on reassessment with that reported for the whole group of patients from which they were recruited (comparative study, Chapter 5). Significant changes in other endpoint measures, notably disease activity (BASDAI), and metrology (BASMI and right and left coronal flexion), were not accompanied by significant changes in spinal position sense. Changes in spinal position sense over the 12 to 18 month time interval did not correlate significantly with changes in indices of disease progression (BASMI, BASDAI,BASFI) over this period. Spinal position sense does not, therefore, appear to be significantly affected by disease processes over a 12 to 18 month time period in patients with mild AS.

7.5 SUMMARY

Spinal position sense and other endpoint measures were assessed in 27 AS patients with mild disease on two separate occasions with a mean time interval of 13.66 months. Subjective feedback from patients and significant changes in objective measures of metrology and disease activity indicated active, progressive disease during this period. There were, however, no significant changes in spinal position sense or in measurements of spinal posture. Similarly, there was no evidence of an association between changes in spinal position sense and in indices of metrology (BASMI), disease activity (BASDAI) or function (BASFI) over time. AS has a generally slow progression and this study suggests that longer follow-up periods may be necessary to elicit longitudinal changes in posture and position sense and to determine any association between these.

CHAPTER 8

FINAL SUMMARY, DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

This final chapter summarises the findings and main conclusions of the experimental studies undertaken in this work. It also includes a final discussion of key issues and provides recommendations for further research in the area of spinal proprioception.

8.1 SUMMARY

The final summary of this work is described within the framework of the stated objectives (Chapter 1, p. 85).

I To develop and validate a reliable method of assessing spinal proprioception suitable for use in a clinical setting

The newly-developed technique was designed to assess absolute error in reproducing spinal postures under naturalistic, self-paced conditions. Previous studies suggest that sensors attached to the skin overlying the spine in the manner described in these studies can provide accurate measurements of angular movements of the underlying spine. Differences in measurements obtained from these sensors in repositioning tasks would therefore appear to represent valid measurements of real changes in spinal positioning.

Reliability is a necessary condition for validity (Domholdt 1993), and the studies in this thesis assessed both the strength of association between repeated measurements of spinal repositioning accuracy ("relative" reliability, ICC) and the variability between them ("absolute" reliability, ANOVA and SEM). Position sense measurements at L1 and S2 on return to upright standing from sagittal flexion demonstrated intra-rater reliability in both patients and controls. Similarly, measurements obtained at T1, T7 and L1 on return from right side flexion showed good reliability in both these groups. Repositioning measurements at the aforementioned sites and in the positions specified were associated with high intra-class correlation co-efficients ($\geq$ 0.72) and low standard errors of measurement ($\leq$ 0.79 degrees). They therefore have the greatest practical utility in discriminating between different patient groups or between patients and controls. In addition to providing reliable measurements of spinal position sense the technique developed in these studies is non-invasive and easy to implement. This makes it suitable for

use in a clinical environment provided that the methodological considerations relating to the use of electromagnetic devices are considered in assessment protocols.

II To obtain normative data on spinal position sense in healthy subjects

Spinal position sense acuity in healthy subjects was comparable with that of peripheral joints. It also tended to improve from cephalad to caudad sites and demonstrated a high degree of accuracy and precision at the sacrum. It was better in the coronal compared to the sagittal plane and in right compared to left coronal flexion. There was also a trend for measurements of spinal position sense in upright standing to be more reliable in the right coronal plane compared to the left. These findings suggest a dominance effect that may be associated with handedness. Healthy subjects tended to overshoot spinal positions in coronal and sagittal flexion. Measurements of spinal position sense were little affected by the magnitude of movement traversed in repositioning tasks.

III To investigate the hypothesis that pathological processes in ankylosing spondylitis cause deficits in spinal position sense by:

- comparing spinal position sense in patients and healthy controls
- examining the association between spinal position sense and disease progression endpoint measures in ankylosing spondylitis patients in both cross-sectional and longitudinal studies
- investigating the trainability of spinal position sense in AS patients with mild disease in response to an in-patient rehabilitation programme

Ankylosing spondylitis patients with mild disease did not show significant qualitative or quantitative changes in spinal position sense compared to healthy controls.

There was no substantive association between spinal position sense and spinal posture or indices of disease activity (BASDAI), metrology (BASMI), function (BASFI) and global well-being (BASG-1) in AS patients with mild disease. Several weak but significant correlations between spinal position sense, age, disease duration, the disease activity index (BASDAI) and the metrology index (BASMI) suggested a small improvement in spinal

position sense with increasing disease severity. This may reflect a sensitizing effect of pathological processes or the small effect of differences in the range of movement traversed during testing on position sense measurements.

Statistically significant changes in validated indices of metrology, function, disease activity and global well-being were obtained following an established ankylosing spondylitis in-patient programme. There were, however, no corresponding changes in spinal position sense. This may reflect the lack of specificity of the exercises in the programme in targeting spinal proprioceptive mechanisms. It is also possible that position sense may only have potential for improvement in subjects with measurable deficits.

IV To investigate the association between disease progression, spinal position sense and spinal posture by longitudinal study of AS patients with mild disease

In patients with early AS, disease progression over a 12 to 18 month period was indicated by a statistically significant decline in mobility and an increase in measures of disease activity. Spinal posture and position sense, however, did not change during this time and were therefore unaffected by disease progression. There was also no association between measurements of spinal posture and sagittal position sense. Longitudinal assessment over longer periods of time may be required to determine changes in spinal posture and position sense and any association between these measures and indices of disease.

8.2 FINAL DISCUSSION

8.2.1 Position sense versus movement sense

The chief construct underlying the measurement of proprioception in these studies is that it can be determined by the assessment of repositioning accuracy in reproduction tasks. Although this is one classical clinical test of proprioception, the majority of proprioception studies involve "movement sense" tests which assess thresholds to the perception of slow passive movement. These tests involve very slow angular displacements at velocities of around 0.5 to 2.0 degrees per second which recruit only a small proportion of the potential population of proprioceptive afferents. Tests involving repositioning tasks under naturalistic

self-paced conditions, like those in this current work, recruit a more diverse population of both fast- and slow-adapting afferents and are therefore more likely to assess proprioceptive contributions analagous to those of everyday functional movement (Lephart et. al. 1997). In addition, these tests reduce the requirement for extensive attachment of external apparatus which may provide exteroceptive cues which facilitate position sense.

8.2.2 Qualitative versus quantitative measurement of position sense

In part of this thesis (Chapter 4), position sense was assessed using both the absolute and "signed" error in the performance of repositioning tasks. The former gives an indication of the magnitude of error but ignores its direction; the latter takes into account overshooting or undershooting of target positions and therefore provides qualitative as well as quantitative data. Both techniques have been used previously and both are valid under certain circumstances. However, signed errors when averaged over a group of subjects tend to cancel each over out giving an impression of greater reliability and accuracy than results based on averaged unsigned errors. For this reason, quantitative assessments should be based on the absolute error, and signed errors should be used only to provide qualitative data, for example, to indicate the frequency of undershooting or overshooting of target positions compared to that expected by chance. Other qualitative approaches to position sense measurement, such as the assessment of movement patterns during functional tasks, may emerge as new measures of proprioception particularly in view of recent advances in computerised movement analysis technology. However, some systematic method of quantifying or grading such movements would still be required if they were to be utilised in everyday clinical practice. Quantitative methods of assessing proprioception may not encompass all dimensions of the complex sense of proprioception but this does not invalidate their use. Measurement of force generation in muscles by dynamometry (Domholdt 1993), for example, is a limited assessment of overall muscle performance but nonetheless one which assesses an important component of it.

8.2.3 Subject selection

The controls who took part in these studies were a generic group of hospital and university employees and students within an age range chosen to match that of AS patients. They had

a broad range of both active and sedentary occupations and varying levels of leisure activity. A maximum of three healthy volunteers did not fulfill inclusion criteria for the studies and only one control dropped out of one study. These controls may therefore be taken to be broadly representative of the general population for this age group.

The patients who took part in these studies had all been diagnosed by the modified New York criteria and were selected on the basis of good metrology scores obtained using a validated index (BASMI). These patients were chosen for two reasons:

1) Patients with more advanced disease have stiff, fused spines and may be capable of little regional movement, so measures of regional spinal position sense in such patients would have little validity

2) Patients with mild disease were thought to be more likely to benefit from preventative therapy aimed at improving spinal position sense, posture and mobility

8.2.4 "Halfway" movements in spinal position sense protocols

The work described in Chapters 2 and 4 demonstrated that the requirement to move to "halfway" flexed positions produced measurable changes in regional spinal curvature in both patients and controls and therefore placed demands on regional proprioceptive input as well as vestibular and other extra-spinal contributions to proprioception. Current knowledge on the distribution of the spinal structures which contain proprioceptive afferents suggests a capacity for position sense throughout the different regions of the spine. "Halfway" movements in patients also allowed regional changes in spinal curvature without provoking pain which may help to facilitate position sense by providing antalgic cues.

8.2.5 Spinal position sense in patients with ankylosing spondylitis

Pathological process in AS target spinal entheses which are important sites of receptors providing information on position sense. Patients with mild disease, however, did not have qualitative or quantative deficits in position sense when compared with healthy subjects. This finding may be considered in the context of the mechanisms which may cause position

sense deficits in these patients and which are discussed under the aims and objectives of this work (pp.84-85).

Alteration in afferent input from damaged receptors does not appear to affect spinal position sense in patients. Furthermore, spinal position sense does not deteriorate with advancing disease. As discussed in Chapter 5 (p.181), input from articular receptors may be less important to position sense than that contributed by muscle afferents. This is supported by the relative paucity of afferents in spinal apophyseal joints relative to the the large number found in small paraspinal muscles such as rotatores and multifidus.

Central mechanisms, such as alteration in efference copy due to loss of movement, may be a factor in position sense deficit (pp. 23-24). However, there is no substantive evidence that hyper-or hypomobility of normal or pathological joints affects position sense (pp. 36-37). In the current study, AS patients with mild disease had no deficits in spinal position sense. Furthermore, they had maintained a good range of movement which was reflected in low scores in the metrology index (BASMI). Changes in efference copy secondary to immobility are therefore unlikely to be a potential source of position sense deficit in these patients.

Primary defects in the central calibration of proprioception have been proposed in the aetiology of scoliosis which, like AS, is associated with spinal deformity (pp. 23-24). This theory is supported by research which shows changes in upper limb position sense (Keesen et. al. 1992) and in thresholds to the detection of vibration (Barrack et. al. 1988) in scoliotic patients. There is, however, currently no evidence of central nervous system abnormality or of deficits in peripheral position sense in patients with AS. If deficits in peripheral proprioception were to be found, they may reflect the secondary influence of chronic pain on central processing mechanisms (pp.23-24) rather than any primary CNS defect. The experimental studies in this thesis, however, were unable to detect any deficit in spinal position sense in patients. This suggests either that there are no primary or secondary CNS deficits in the processing of proprioception in ankylosing spondylitis or, that if they exist, they are adequately compensated by other sources of input.

Position sense is usually assessed in conditions associated primarily with trauma and/or degeneration rather than inflammation per se. Deficits are therefore commonly attributed to joint instability perpetuated by abnormal proprioceptive joint input (pp. 34-35). Instability is not, however, classically associated with ankylosing spondylitis since pathological processes tend to stabilise the spine by ossifying spinal entheses.

The healthy lumbosacral spine is intrinsically unstable and highly dependant on local paraspinal musculature for segmental stability (Cholewicki et. al. 1997). In AS, increasing stability of the spine with advancing ossification may therefore result in diminished recruitment of paraspinal musculature. Any resultant local deficit in spinal position sense at this advanced stage of the disease, however, appears rather academic in the absence of any corresponding spinal movement. Local position sense deficits could also, in theory, affect position sense in relatively mobile adjacent spinal sites through a variety of central or peripheral mechanisms (pp.84, 143). Spinal regions adjacent to sites of advanced disease could, for example, become hypermobile and thus influence position sense through the instability mechanisms discussed above.

In practice, however, spinal movement tends to be generally restricted and postural deformity more established in these patients with localised areas of more advanced disease. Consequently, very little regional spinal movement may take place during position sense testing by repositioning tasks (pp. 95-97). Nociceptive input may also invalidate the results of tests in these patients by providing non-proprioceptive cues which facilitate repositioning accuracy. Even if these threats to validity were somehow overcome and deficits in spinal position sense were found, both the potential for, and utility of, proprioceptive rehabilitation by specialised exercise regimes (pp. 36-39) is likely to be considerably reduced in these patients with advanced stiffness and deformity.

8.3 MAIN CONCLUSIONS

The following conclusions may be drawn from these studies:

- Reliable measurements of spinal position sense can be obtained using an electromagnetic movement sensing device and a skin surface technique

- Spinal position sense is of similar accuracy to that of peripheral joints

- The magnitude of movement traversed in spinal position sense tests does not significantly affect position sense measurements

- Spinal position sense in ankylosing spondylitis patients with mild disease is quantitatively and qualitatively comparable to that of healthy controls

- An in-patient programme incorporating mobilising, strengthening and co-ordination exercises does not significantly affect spinal position sense in ankylosing spondylitis patients with mild disease

- Ankylosing spondylitis patients with mild disease do not demonstrate significant changes in posture or spinal position sense in response to disease progression over a 12 to 18 month period

8.4 RECOMMENDATIONS FOR FURTHER STUDIES ON SPINAL PROPRIOCEPTION

8.4.1 Measurement reliability

Further work could be undertaken to improve the reliability of the technique developed for use in these studies. Reliability may be enhanced by the selection of different sensor sites or alternative methods of attachment. The less prominent spinous process at T2, for example, may provide more reliable and precise measurements of position sense than those obtained at the more uneven and protuberant spinous process of T1. Work also needs to be undertaken to establish the inter-rater reliability of the technique. This is particularly important for the assessment of spinal position sense in patients with long-standing progressive disease, such as ankylosing spondylitis, where different therapists may be involved in the assessment of patients over time.

8.4.2 Sample size

The wide variation in spinal position sense measurements in both patients and healthy controls, as indicated by these studies, suggests that large numbers of subjects would need to be studied if significant changes in spinal position sense are to be detected between groups. Cross-sectional studies of position sense in patient populations often use relatively small sample sizes of approximately 10 to 20 subjects (for example, Loudon et. al. 1997, Gill and Calaghan 1998) and variations in measurements between individuals within these small groups may mask differences between the groups. An additional consideration is that calculation of the sample size necessary for statistical tests to have sufficient power, depends on knowledge of the "effect size" or size of the smallest difference in the dependant variable that would be clinically meaningful (Altman 1980). Proprioception has rarely been assessed in conjunction with other endpoint measures and the clinical relevance of small changes in measures of position sense is unknown. The lack of substantive evidence of a relationship between proprioception and other endpoint measures may reflect the insensitivity of measures (many of which have not been validated) rather than a true absence of association. Further work therefore needs to be carried out to determine the

relationship between proprioceptive measures and other validated and sensitive endpoint measurements such as function. This would help to establish effect size and therefore the sample size required for statistical tests to have sufficient power in experimental studies of proprioception.

8.4.3 Further studies on patients with AS

No evidence of qualitative or quantitative deficits in spinal position sense was found in AS patients in any of the studies undertaken in this work. It cannot be inferred, however, that there are no deficits in afferent proprioceptive input in AS. Abnormalities may exist but be compensated by redundancy in populations of proprioceptive afferents unaffected by disease processes. Alternatively, proprioceptive deficits may be compensated by "retensioning" of ligaments, joint capsules and other soft tissues due to the processes of inflammation and ossification. If deficits do occur, and can be adequately compensated for, then they are unlikely to contribute to spinal deformity in these patients.

In a group of patients studied over a 12 to 18 month period, there was no overall trend towards reduction in the normal lumbar lordosis, which may feature early in the process of spinal deformity. However, although there are clinically discernible trends in the overall pattern of disease (Carett et. al. 1983, Gran and Skomsvoll 1997), AS is characterised by large variations in disease activity between individual patients. Goodacre et. al. (1991), for example, monitored a group of 22 AS patients at monthly periods over an interval of one year and reported "marked heterogeneity" in the disease activity profiles of individual patients. This variability and the generally slow progression of AS over time, suggests that patients would need to be followed-up for longer periods if any association between spinal position sense and postural change is to be investigated. The study of spinal position sense in patients with advanced disease, and therefore established postural deformity, is, however, unlikely to be of any real value (p. 225).

Focusing on specific subsets of AS patients, as in the current study, is most likely to elucidate the causes of postural change. For example, a longitudinal study of recently-diagnosed patients with hip involvement may help to establish if there is a relationship between hip disease and spinal deformity. The few current explanations of postural

deformity have an antalgic basis and suggest that early flattening of the lumbar lordosis is an attempt to relieve painful loading on posterior lumbar facet joints. A study involving the longitudinal assessment of lumbar pain and changes in lumbar curvature may help to isolate this as a factor in the development of spinal deformity. Single case studies of individual patients may also help to isolate the causes of spinal deformity and serve as a basis for larger studies of homogenous groups of patients.

The absence of significant changes in spinal position sense in patients following an in-patient programme may reflect the lack of specificity of the exercises in the programme in targeting proprioceptive mechanisms. In addition, there is no substantive evidence that spinal or peripheral proprioception can be enhanced by specialised rehabilitation in the absence of any measurable deficit . Further studies on the effect of such programmes on healthy subjects and groups of patients with identifiable loss of proprioceptive acuity need to be undertaken in order to ascertain the trainability of proprioception in these populations.

8.4.4 Patients with other spinal conditions

Published studies of proprioception in low back pain have broad inclusion criteria and therefore involve generic groups of low back pain patients with diverse pathology (Parkhurst and Burnett 1994, Gill and Callaghan 1998). Although these studies report deficits in proprioception the underlying mechanisms are unknown. Peripheral mechanisms may include quantative or qualitative changes in afferent input from articular and peri-articular structures. Changes in input may be directly misinterpreted by the central nervous system or, indirectly, may affect position sense through central or local segmental mechanisms. The sensitivity of muscle spindle afferents, for example, may be affected at either a central or segmental level by changes in the input of joint receptor afferents (pp. 21-22). Primary (due to pathological damage) or secondary (due to loss of movement or pain) changes in afferent input may also lead to alterations in centrally generated efferent copy and thus affect the sensori-motor integration of proprioception (pp.23-24).

The structures and mechanisms responsible for proprioceptive deficits need to be precisely determined before the issue of rehabilitation of position sense can be properly addressed. This may be assisted by further research in the basic sciences, such as the relatively recent

work on the anatomical distribution of spinal afferents (p. 54). Clinical studies underpinned by a definate theoretical rationale, and which therefore assess specific subsets of patients, will also assist in this process. These should help to identify those patients most likely to benefit from proprioceptive rehabilitation There is some evidence, for example, that proprioception and joint stability are closely related. Deficits in proprioception have been reported when the stability of a joint is compromised by pathology or trauma (pp. 31-35). Disruption of normal physiological movement under conditions of joint instability appears to impair proprioception although underlying mechanisms are poorly understood. Restoration of the integrity of joints, for example, by ligament surgery has been shown to restore proprioceptive acuity (Harter et. al. 1992, Co et. al. 1993). It may be useful in future studies of spinal position sense in low back pain to classify patients on the basis of lumbar stability. Clinical signs of lumbar instability, such as those suggested by Norris (1995), may help to differentiate between spinal patients with destabilising pathology and those with stabilising pathology, and study of such patient groups may provide useful information regarding the potential cause of proprioceptive deficit. Understanding of the mechanisms involved and the clinical significance of findings will also be enhanced by the assessment of position sense in conjunction with other related endpoints.

8.5 SUMMARY OF RECOMMENDATIONS FOR FURTHER RESEARCH

- Further reliability studies including investigation of inter-rater reliability
- Studies involving simultaneous assessment of position sense and other endpoint measures in order to establish "effect size" and therefore sample size in proprioceptive studies
- Elongated longitudinal studies of position sense and posture in ankylosing spondylitis patients to determine any association between these
- Further long-term longitudinal studies on homogenous subsets of ankylosing spondylitis patients to determine the mechanisms underlying postural change
- Investigation of the association between instability and position sense in back pain patients with destabilising pathology

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APPENDIX 1

RADIOGRAPHIC AND MULTI-DIMENSIONAL ENDPOINT MEASURES USED IN THE ASSESSMENT OF ANKYLOSING SPONDYLITIS

The Bath Ankylosing Spondylitis Radiographic Index (BASRI) is a radiographic index based on the Bath Ankylosing Spondylitis Radiology Index for the Spine (BASRI-s) and scoring of sacroiliac joints (from an anteroposterior radiograph) using the New York criteria (Tables 45 and 46).

Mackay K, Mack C, Brophy S, Calin A, (1998), The Bath Ankylosing Spondylitis Radiology Index (BASRI), Arthritis Rheum; 41:2263-2270

Score	Grade	System applies to both the lumbar and cervical spine (grade each as 0-4)
0	Normal	No change
1	Suspicious	No definate change
2	Mild	Any number of erosions, squaring or sclerosis, with or without syndesmophytes, on ≤ 2 vertebrae
3	Moderate	Syndesmophytes on ≥3 vertebrae, with or without fusion involving 2 vertebrae
4	Severe	Fusion involving ≥3 vertebrae
Lumbar spine: examine both the anteroposterior and lateral radiographs together. The score for the lumbar spine is a composite of the two views. If the two views differ, the overall score will relate to the view with the greatest change Cervical spine: examine lateral radiograph only Mean time taken to score one set of radiographs is 30 seconds. Maximum possible score, incorporating SI scoring system (below), is 12.		

Table 45 - The Bath Ankylosing Spondylitis Radiology Index for the Spine (BASRI-s)

Score	Grade	New York grading of sacroiliac joints
0	Normal	Normal
1	Suspicious	Suspicious changes, blurring of joint margins
2	Mild	Mimimal abnormalities. Blurring of margins with small localised areas with erosions or sclerosis without alteration in joint width
3	Moderate	Unequivocal abnormality. Moderate or advanced sacro-ilitiis with one or more of the following: erosions, sclerosis, widening, narrowing or partial ankylosis
4	Severe	Severe abnormality Total ankylosis

Table 46 - New York grading of sacroiliac joints

THE BATH ANKYLOSING SPONDYLITIS METROLOGY INDEX (BASMI)
(Jenkinson et. al. 1994, Jones et. al. 1995)

This is a multi-dimensional index in which five clinical measurements are used to obtain a composite score.

1. Tragus-to-wall

The patient stands with their back to the wall with heels and buttocks touching it. The knees are kept straight and the shoulders back. Keeping the eyes forward, the head is placed as far back as possible while keeping the chin in. The linear distance between the tragus of the ear and the wall is measured in centimeters using a perspex ruler mounted on a flat base which is held against the wall.

2. Lumbar flexion (Modified Schober technique)

With the patient in relaxed standing, arms by the sides, a mark is placed at S2 at the level of the dimples of Venus. Further marks are placed 5 cm below and 10 cm above this mark. The patient is asked to bend forward as far as possible, initially keeping the knees straight, and then flexing the knees slightly to relax the hamstrings. The distance between the two outer marks is measured in centimeters using a tape measure.

3. Intermalleolar distance

The distance between the medial malleoli is measured with a tape measure (cm) with the patient lying in supine. The feet are kept pointing upwards to control for hip rotation.

4. Cervical rotation

Cervical rotation is measured with a gravity action goniometer. The patient lies supine with the head in the neutral position and the goniometer placed centrally on the forehead. The mean result of right and left cervical rotation is calculated.

5. Lumbar side flexion

This is assessed by fingertip to floor distance in full lateral flexion with the knees straight and without flexing forward. The patient flexes in the coronal plane using the middle finger to slide a bar down a vertically mounted perspex ruler placed on the floor. The difference between start and finish readings is taken as a measure of coronal lumbar flexion. The mean of right and left measurements is calculated for the BASMI index.

The BASMI score of each measurement is obtained from the table shown overleaf (Table 47). The overall BASMI score is calculated by adding all the BASMI scores and dividing the result by five to give an average score.

No.	NAME	0	1	2	3	4	5	6	7	8	9	10
1	**TRAGUS TO WALL (CM)**	<10	10-12	13-15	16-18	19-21	22-24	25-27	28-30	31-33	34-36	≥ 37
2	**LUMBAR FLEXION (CM)**	>7	6.4-7.0	5.7-6.3	5.0-5.6	4.3-4.9	3.6-4.2	2.9-3.5	2.2-2.8	1.5-2.1	0.8-1.4	≤ 0.7
3	**INTERMALLEOLAR (CM)**	≥120	110-119	100-109	90-99	80-89	70-79	60-69	50-59	40-49	30-39	≤ 30
4	**CERVICAL ROTATION (CM)**	> 85.0	76.6-85.0	68.1-76.5	59.6-68.0	51.1-59.5	42.6-51.0	34.1-42.5	25.6-34.0	17.1-25.5	8.6-17.0	≤ 8.5
5	**LUMBAR SIDE FLEXION (CM)**	> 2.0	18.0-20.0	15.9-17.9	13.8-15.8	11.7-13.7	9.6-11.6	7.5-9.5	5.4-7.4	3.3-5.3	1.2-3.2	<1.2

TABLE 47 - The Bath Ankylosing Spondylitis Metrology Index (BASMI)
The index is obtained by taking the average BASMI score of the five clinical measurements

SCORING OF BASGI, BASDAI AND BASFI

Scores are derived from the linear distance (cm) along each 10 cm visual analogue scale to the vertical mark placed by the patient.

BAS-G	Index score is the average score of the two questions
BASG-1	Is the score of the first question only
BASDAI	The scores of questions 5 and 6 are averaged. The total score is the average of this score and the scores of the remaining questions
BASFI	The average score of the ten components

The Bath Ankylosing Spondylitis Patient Global Score

(BAS-G)

1. Please place a vertical mark on the scale below to indicate the effect your disease has had on your well-being over the last week.

NONE _____ VERY SEVERE

2. Place a vertical mark on the scale below to indicate the effect your disease has had on your well-being over the last **six months.**

NONE _____ VERY SEVERE

The Bath Ankylosing Spondylitis Disease Activity Index (BASDAI)

(a) If you are currently taking medication for your AS, please give the name and dose that is on the bottle or packet:

_____

(b) Place a mark on the line below to indicate the effectiveness of the medication in relieving your symptoms

NO EFFECT _____ VERY EFFECTIVE

PLEASE PLACE A MARK ON EACH LINE BELOW TO INDICATE YOUR ANSWER TO EACH QUESTION, RELATING TO THE PAST WEEK.

EXAMPLE:

NONE ——|—— VERY SEVERE

(1) How would you describe the overall level of fatigue / tiredness you have experienced?

NONE _____ VERY SEVERE

(2) How would you describe the overall level of AS neck, back or hip pain you have had?

NONE _____ VERY SEVERE

(3) How would you describe the overall level of pain/swelling in joints other than neck, back or hips you have had?

NONE _____ VERY SEVERE

(4) How would you describe the overall level of discomfort you have had from any areas tender to touch or pressure?

NONE _____ VERY SEVERE

(5) How would you describe the overall level of morning stiffness you have had from the time you wake up?

NONE _____ VERY SEVERE

(6) How long does your morning stiffness last from the time you wake up?

0 hrs | 1/2 | 1 | 1 1/2 | 2 or more hrs

The Bath Ankylosing Spondylitis Functional Index (BASFI)

PLEASE DRAW A MARK ON EACH LINE BELOW TO INDICATE YOUR LEVEL OF ABILITY WITH EACH OF THE FOLLOWING ACTIVITIES DURING THE PAST WEEK:

EXAMPLE:

EASY ——————|—————— **IMPOSSIBLE**

N.B An aid is a piece of equipment which helps you to perform an action or movement

1) Putting on your socks or tights without help or aids (e.g sock aid)

EASY _____ IMPOSSIBLE

2) Bending forward from the waist to pick up a pen from the floor without an aid

EASY _____ IMPOSSIBLE

3) Reaching up to a high shelf without help or aids (e.g helping hand)

EASY _____ IMPOSSIBLE

4) Getting up out of an armless dining room chair without using your hands or any other help

EASY _____ IMPOSSIBLE

5) Getting up off the floor without help from lying on your back

EASY _____ IMPOSSIBLE

6) Standing unsupported for 10 minutes without discomfort

EASY _____ IMPOSSIBLE

7) Climbing 12 - 15 steps without using a handrail or walking aid. **One foot on each step**

EASY _____ IMPOSSIBLE

8) Looking over your shoulder without turning your body

EASY _____ IMPOSSIBLE

9) Doing physically demanding activities (e.g physiotherapy exercises, gardening or sports)

EASY _____ IMPOSSIBLE

10) Doing a full days activities whether it be at home or at work

EASY _____ IMPOSSIBLE

APPENDIX 2

PATIENT INFORMATION SHEET - RESEARCH ON THE SPINE

Introduction

Thank you for considering helping with a research project looking at movements and positioning of the spine. The following information is designed to help you make an informed decision about whether you would like to take part. There is no obligation to take part and if you decide not to, it will not affect your treatment in any way. If you do decide to take part, you can change your mind at any time without giving any reasons and this, again, will not affect your treatment in any way. The researcher will obtain the permission of your hospital consultant if you do decide to take part.

Aim of the research

The aim of this research is to measure movements and positions of the spine in people with and without ankylosing spondylitis and to determine if there are any differences between the two groups. The results should provide helpful information on the reasons for changes in the alignment of the spine in people with ankylosing spondylitis. This information may enable us to develop more effective treatment programmes for people with this back condition.

Procedures involved

At the start of the tests the researcher will ask you some questions about your current back problem and your previous medical history. For example, you will be asked whether you have ever broken any of your bones and how long you have had ankylosing spondylitis.

The tests involve putting some small movement sensors on your back with tape. These sensors give information to a computer on how you are moving and positioning your spine. Once the equipment is set up and some preliminary measurements have been taken, you will be asked to wear a blindfold so that you are unable to judge your movements and positioning by sight. You will be asked to do tests which involve bending forwards and sideways with short rests between each movement while wearing the blindfold. Each test lasts for less than half a minute and the blindfold will be removed between each one. The whole procedure will take about an hour.

You may be asked to come back again for the same measurements in two weeks time if you are an out-patient or, at the end of the course if you are an in-patient. There are no known side-effects to the research and it will not interfere with your treatment in any way. The research is not painful and any movements you are asked to do will be within your painfreee range of movement. However, should you experience pain or discomfort during the tests please tell the researcher. Testing can be stopped at any time and this will not affect your treatment in any way.

A few people might decide that they would like to take part but the researcher may decide that they are not suitable on this occasion. If this happens to you the researcher will explain why.

The information you give to the researcher will be treated as strictly confidential. Your name will not be kept on any records about you - you will be given a code number instead.

If you do decide to take part in the research you will be asked to sign a form in which you give your consent to take part.

If you have any questions about the research please do not hesitate to contact Annette Swinkels, the principal researcher, who is based at the address below.

Thank you

Annette Swinkels
School of Physiotherapy and Occupational Therapy

ADMINISTERED SCREENING FORM

(Form for controls similar but without reference to AS or AS specific pathology)

Date:

Name: **Age:** **Code:**

Address:

( ) **In-patient**

( ) **Out-patient**

Occupation:
Working pattern eg. night shifts:

When was A.S. first diagnosed ?

How long do you think you have had A.S. ?

When did you last have an x-ray of your spine ? Where ?

Have you ever had the following ? -

	No	Yes	Details
Neurological disorder	( )	( )	
Diabetes	( )	( )	
Operation/injury to the spine/lower limbs/hips	( )	( )	
Problems with your balance	( )	( )	
Problems with your hearing	( )	( )	
Problems with your eyes (iritis)	( )	( )	
Achillis tendinitis/plantar faciitis	( )	( )	
Currently receiving physiotherapy for AS ?	( )	( )	
Currently receiving physiotherapy for any other conditions ?	( )	( )	
Have you had any operations or been diagnosed as having any medical conditions ?	( )	( )	

APPENDIX 3 - LESS WELL-KNOWN STATISTICAL TESTS USED IN EXPERIMENTAL STUDIES

1.0 Nested analysis of variance

This is a hierachical repeated measures within-subject analysis of variance which treats subjects as a fixed effect at the top level with assessment sessions nested within subjects.

$$F \text{ statistic} = \frac{\text{Mean square between tests within sessions + mean square between sessions}}{\text{Mean square between sessions}}$$

Level of significance (p value) is derived from the F statistic.

2.0 Standard error of measurement (SEM)

An estimate of the precision of measurement in the relevant units eg. degrees.

$$SEM = s\sqrt{1 - r}$$

s = Standard deviation
r = ICC (2,1)

95% confidence limits around a given measurement = ± 2 x SEM.

3.0 Tukey's Honestly Significant Difference Test (HSD)

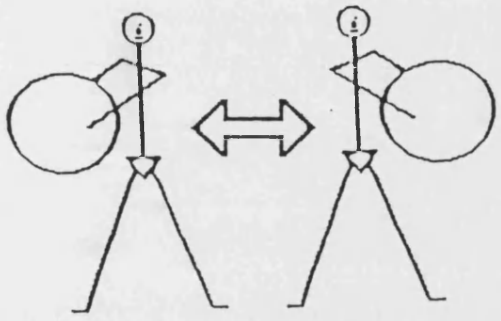
This test can be used for multiple post-hoc comparison of groups which demonstrate significant differences on analysis of variance. The HSD test identifies the minimum true value by which two means must "honestly" differ to achieve statistical significance.

APPENDIX 4 EXAMPLES OF EXERCISES IN ANKYLOSING SPONDYLITIS

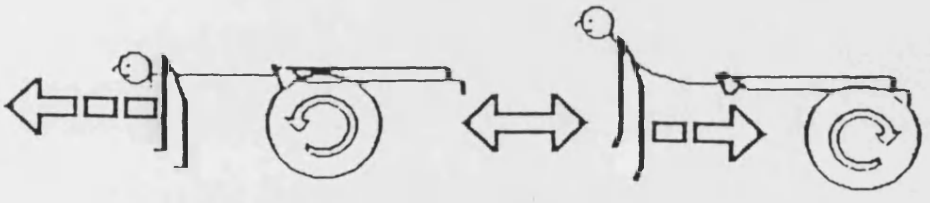
IN-PATIENT PROGRAMME

at the Royal National Hospital for Rheumatic Diseases, Bath, UK.

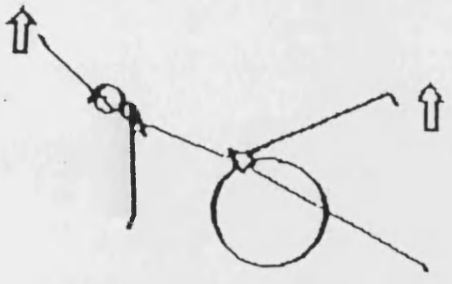
STRENGTHENING AND MOBILISING EXERCISES
INVOLVING SPINAL COORDINATION



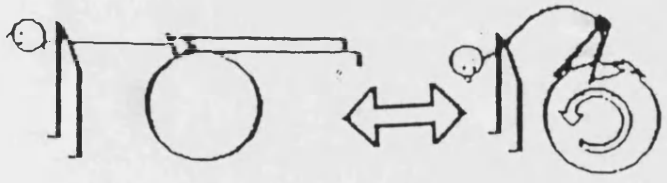
STANDING -
HOLDING BALL
Twist trunk to
alternate sides



LYING OVER BALL
Walk forwards
on hands and
return

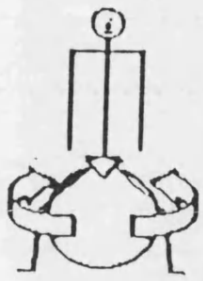


NEXT - Lift alternate arms
NEXT - Lift alternate legs
NEXT - Lift arm and opposite leg as shown

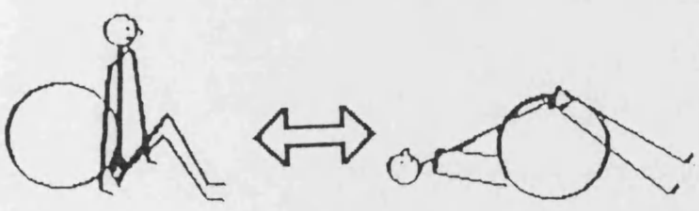


NEXT - Move ball
forwards
using legs

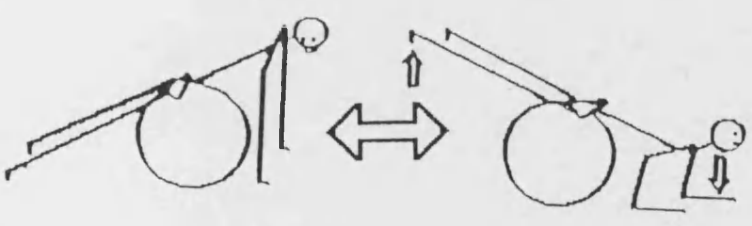
STRENGTHENING AND MOBILISING EXERCISES INVOLVING SPINAL COORDINATION (Continued)



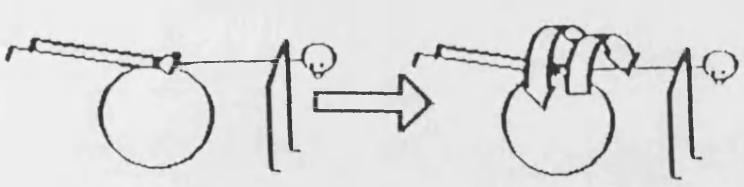
SITTING ON BALL - Roll ball in circles to alternate sides



SITTING ON BALL - Move to lie back over ball



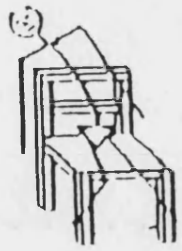
LYING OVER BALL - ARMS STRAIGHT Bend elbows lifting feet



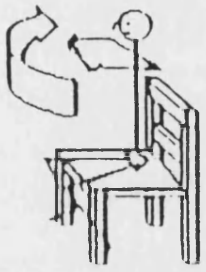
LYING ON BALL - Twist pelvis to alternate sides

KNEELING BY BALL - Roll ball to alternate sides

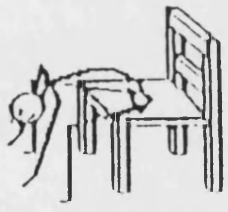
SPINAL MOBILISING EXERCISES IN SITTING



SITTING - LEGS FIXED ON CHAIR
Bend trunk to alternate sides



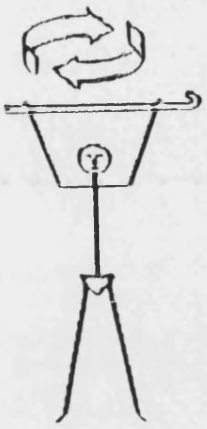
SITTING - LEGS FIXED ON CHAIR - OPPOSITE ELBOWS GRASPED
Turn trunk to alternate sides



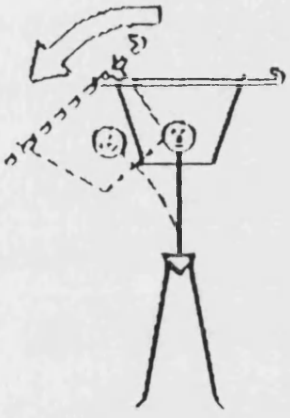
SITTING -
Bend forwards breathing out

SITTING -
Bend backwards over chair back

SPINAL MOBILISING EXERCISES USING A STICK



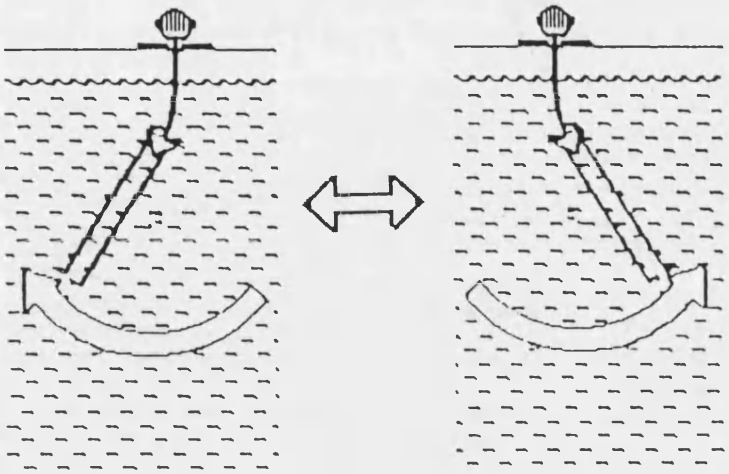
STANDING - HOLDING STICK ABOVE
Turn trunk to alternate sides



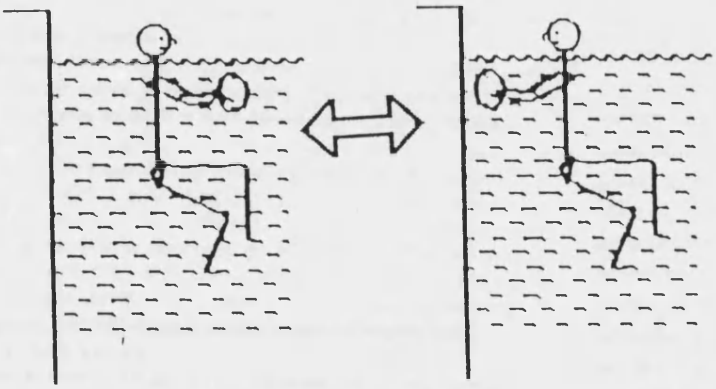
STANDING - HOLDING STICK ABOVE
Bend trunk to alternate sides

STANDING - HOLDING STICK IN FRONT
Turn trunk to alternate sides

SPINAL MOBILISING EXERCISES IN WATER



FACE WALL - ARMS FIXED ON SIDE OF POOL
Swing to alternate sides



SQUAT - BACK TO SIDE OF POOL - HOLDING BAT
Turn to alternate sides

SPINE Volume 23, Number 5, pp 590–597

Regional Assessment of Joint Position Sense in the Spine

Annette Swinkels, MSc,* and Patricia Dolan, PhD†

Study Design. A test–retest design was used to assess the reproducibility of position sense measurements of the spine recorded at T1, T7, L1, and S2.

Objectives. To measure position sense at four spinal levels in healthy volunteers and to determine if this varies on a day-to-day basis. The overall purpose is to provide baseline data for studying position sense of the spine in patients with spinal lesions.

Summary of Background Data. Position sense, which is one component of proprioception, is assessed by the ability to reposition the body after displacement. In peripheral joints, position sense is accurate to within a few degrees. Studies on the spine suggest similar accuracy, but most have used indirect methods of measurement that often incorporate unusual extraneous cues.

Methods. Spinal position sense was assessed in 20 healthy volunteers using an electromagnetic movement sensor system, the 3-Space Fastrak (Polhemus, Colchester, VT), to measure absolute error in actively reproducing upright and flexed positions during movements in both coronal and sagittal planes. Three randomized measurements were taken for each position in one testing session, and measurements were repeated in all participants 2 weeks later.

Results. Same-day measurements indicate that spinal position sense is reproducible in upright postures to within a mean of 3.79 ± 2.56 for movements in the sagittal plane and 2.26 ± 1.59° for movements in the coronal plane. Corresponding measurements for flexed postures are 5.27° ± 3.47° and 3.70 ± 2.62°, respectively. Intraclass correlation coefficients between repeated measurements are generally good in the sagittal plane but are affected by side dominance in the coronal plane. Also, repositioning errors tend to increase on ascending the spine. Repeat measurements taken 2 weeks later show similar values.

Conclusions. 1) Healthy volunteers were able to reposition their spine with considerable accuracy as measured with the 3-Space Fastrak; 2) this ability does not change significantly on a day-to-day basis; and 3) the 3-Space Fastrak offers a noninvasive and accurate method for the measurement of spinal position sense.
[Key words: movement analysis, position sense, proprioception, spine] **Spine 1998;23:590–597**

From the *Faculty of Health and Social Care, University of the West of England, and the †Department of Anatomy, University of Bristol, Bristol, United Kingdom.
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Acknowledgment date: March 13, 1997.
Acceptance date: July 23, 1997.
Device status category: 1.

"Proprioception" describes those sensations generated within the body that contribute to awareness of the relative orientations of body parts, at rest and in motion, and that are fundamental to the normal control of human movement. Receptors in muscles, tendons, ligaments, joints, and skin are now all believed to play a role in supplying proprioceptive input.[14,15,26,27] However, their relative contribution would appear to vary at different sites of the body. Cutaneous receptors, for example, appear to play a more important role in proprioception of the hand than in other joints.[28] In the spine, afferent nerves capable of conveying proprioceptive information have been located in many structures, including interspinous, supraspinous, and flaval ligaments,[41] the thoracolumbar fascia,[42] lumbar intervertebral discs,[43] paraspinal muscles,[13,43] and intrinsic postvertebral muscles.[3]

Proprioception is classically measured by two types of tests designed to assess either position sense or movement sense. Position sense tests require subjects to reproduce previous positions or ranges of movement achieved either actively through isotonic muscle work or passively by an external device.[5–7,25,36] Movement sense is assessed by determining thresholds to the perception of movement and its direction, where the movement is applied either at a constant velocity[6,7,36] or as a constant stimulus.[16,21,22] In constant-velocity methods, slow passive movement is applied and proprioception is reported in terms of angular or distance thresholds of joints to the perception of that movement. In the constant-stimulus approach, discrete or oscillatory vibration-type movements are used, and proprioception is derived from the intensity of stimulus necessary to obtain a report of the perception of movement. These proprioceptive tests frequently involve the use of externally applied mechanical, electromechanical, or electromagnetic assemblies to measure or apply the movement, and subjects are usually blindfolded because visual input is not included in Sherrington's[35] original concept and is not considered part of proprioception *per se*.[14]

Because of the great importance proprioception plays in normal joint function, a considerable body of work has been devoted to its assessment. Much of this has concentrated on the measurement of movement sense. In healthy people, mean movement sense thresholds have been reported to lie between 0.2° to 2.8° at the elbow, 0.3° to 1.8° at the shoulder, and 1.2° to 5.9° at the

knee.[6,7,9,10,17,36] Relatively fewer studies have been conducted to determine position sense, but where this has been measured results suggest that mean repositioning accuracy at the knee lies between 2.4° and 5°, with higher values being reported for the elbow.[6,25,36,37] Recent work suggests that position and movement sense may be impaired in the presence of joint disease.[7,25,29,31] Consequently, an improvement in proprioception is considered by many as an essential part of rehabilitation.[8,18,20] This association between joint disease and proprioceptive ability has led to a growing interest in recent years in measuring proprioception in the spine. A number of studies have determined position sense, either in the trunk as a whole,[4,19,40] or in the lumber[29] or cervical[31,32,39] spine. In general, these studies report position sense values similar to those of peripheral joints.

In most of these studies, indirect measurement methods were used to assess spinal proprioception. Taylor and McCloskey,[40] for example, assessed trunk proprioception by the ability of subjects to relocate the position of their big toe by turning to it with their head. Revel et al[31,32] used a light beam mounted on a helmet and projected onto a target grid to measure position sense accuracy in the cervical spine. Similarly, Jacobs et al[19] used a light beam and transparent ruler to determine subjects' ability to center T1 over the pelvis after 10-cm deviations from midline in the coronal plane. Angular measurements at T1 were subtended from the sacrum. Using a similar methodology but different measurement system, Ashton-Miller et al[4] used a two-camera movement analysis system incorporating the use of infrared markers at the head, T1, and T8. A drawback of some of these studies is that they involve the physical attachment of substantial pieces of apparatus to provide either movement or restraint. Extraneous cues may, in some circumstances, facilitate proprioceptive acuity.[5]

This study attempts to assess the position sense component of proprioception using an electromagnetic movement sensor system, the 3-Space Fastrak (Polhemus, Colchester, VT), which is capable of direct measurement of spinal motion and requires minimal physical contact of apparatus to the test subject. A further advantage of this technique is that regional variations in proprioceptive ability can be assessed. This would be particularly useful in the assessment of patients with localized spinal disease. The 3-Space Fastrak, a three-dimensional motion analysis device, consists of a transmitter (the "source") of pulsed electromagnetic waves and four receivers ("sensors") of these waves. The system is capable of measurements in three planes to an accuracy of 0.15° when the receivers are within 81 cm of the source. A sampling frequency of 15 Hz was obtained when all four sensors were used. A similar device, the 3-Space Isotrak (Polhemus, Colchester, VT), has been used to measure lumbar spinal movements *in vivo* in healthy people and patients.[1,11,33,34] The main objective of this report is to describe the use of the 3-Space Fastrak in the measurement of spinal position sense in the coronal and sagittal planes and to assess the reproducibility of the method on a within-day and day-to-day basis. Ethical permission for this study was obtained from the Wiltshire and Bath Health Authority.

Table 1. Physical Characteristics of Subjects (12 Male/8 Female)

	Height (m)	Weight (kg)	Hand Dominance (R/L)
Mean	1.72	67.8	17/3
Range	1.57–1.85	53.07–82.55	

■ Methods

Subjects. Twenty healthy people gave informed consent to take part. These were employees of university or hospital departments (eight women, 12 men) whose ages ranged from 23 years to 52 years (mean, 33.6 years). Before participation in the study, they completed a medical questionnaire to ensure that they had no history of the following: trauma, surgery or disease of the spine or limbs, diabetes, or neurologic disorders, because these conditions may have an effect on proprioceptive ability. Volunteers who had problems with balance, hearing, or vision (not corrected by glasses) were also excluded for the same reason. Measures were taken of height and weight, and a record made of right- or left-hand dominance. Table 1 gives the physical characteristics of people who took part in the study.

Placement of Fastrak Sensors and Source. Volunteers were asked to stand with the feet sufficiently apart to enable comfortable and safe full spinal movements in sagittal and coronal planes. Distances between midheel and big toes were recorded so that the same stance was achieved on retesting. The location of the midpoint of the spinous processes of T1, T7, L1, and S2 was established by palpation down the spine with the person in a relaxed, semiflexed position. S2 was located between the midpoints of the dimples of Venus. Sensors were applied in this semiflexed position to minimize displacement resulting from skin traction in the fully flexed position. At the upper three sensor locations, a strip of Hypafix tape (Smith and Nephew, Hull, England), 5 cm × 1.5 cm, was attached to the skin over the relevant spinous process and a strip of double-sided tape was placed over the top for attachment of the sensor. At T7 and L1, a Perspex baseplate (2 cm × 1 cm) was fixed to the double-sided tape before attaching the sensor. This enabled the sensors to move freely without being impeded by the muscle mass on either side. Horizontal strips of Hypafix above and below each sensor helped to hold them securely in place during movement. At S2, a square of Hypafix was placed under a 4-cm × 4-cm Perspex plate that provided a firm, flat surface for the attachment of the sensor.[1,11] Where appropriate, a record was kept of any skin features to assist future placement of sensors. Sensors were applied with their leads emerging to the right. The weight of the leads was supported by a cradle of transpore tape situated approximately 8 cm to the right of each sensor.

Electromagnetic waves decay as the distance from source to sensor increases. Also, any metal in the proximity of a magnetic

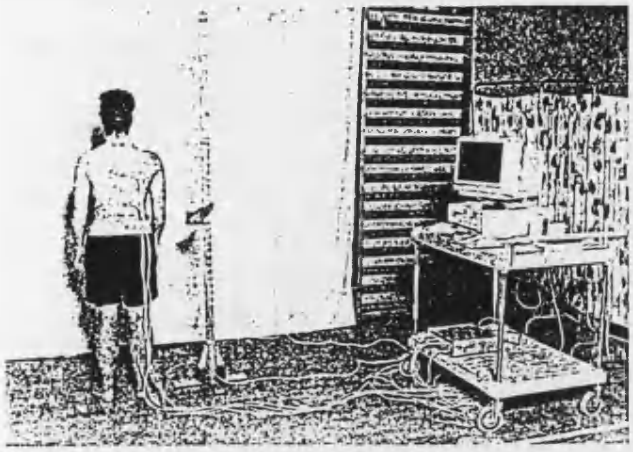

Figure 1. Experimental setup for spinal position sense testing.

field can cause changes in that field. For this reason, all experiments were carried out in a laboratory where there were no large metal objects near the volunteer. Furthermore, the Fastrak source was mounted on a wooden stand that was placed next to the volunteer during testing. The height of the stand could be adjusted so that all sensors remained within the optimum operational range throughout the testing procedure. Figure 1 shows the experimental setup. Preliminary calibration of the Fastrak equipment in this environment demonstrated that there was little loss of angular resolution, provided the distance between source and sensors remained less than 81 cm.

Experimental Protocol. Joint position sense was measured by assessing a person's ability to reproduce the upright standing posture and positions in the sagittal and coronal plane. With arms crossed over the chest and fingertips on shoulders, participants were asked to stand in a relaxed upright posture and then instructed either to flex forward in the sagittal plane, or to flex to the right or left in the coronal plane "as far as you comfortably can." These movements were completed once each in random order, and participants were asked to return to their "exact upright posture" on completion of each. These "full range" movements were carried out to establish the available range of movement, to ensure that participants had adopted a stable stance for all ranges of movement and to enable them to gauge "halfway" positions for subsequent tests. In the next part of the protocol, three tests were performed in random order for each of the movements—forward flexion, left side flexion, and right side flexion. Blindfolded participants were asked to move to a "halfway" position and to maintain this for 3 seconds before returning to their exact upright starting posture. After a further 3-second interval, participants were instructed to return to their exact previous "halfway" position before returning once again to their "exact upright posture." All measurements were repeated 2 weeks later at the same time of day. Participants were tested at least 3 hours after rising to minimize the effects of any diurnal variation in spinal mobility.

Determination of Position Sense. The absolute difference in angle between successive attempts at reproducing "halfway" positions was calculated for each sensor and used as a measure of active position sense in forward, left, and right side flexion. Similarly, the absolute difference between initial upright standing readings and the first return to upright standing from these movements was calculated to determine active position sense in the upright posture. The angular position of each sensor for each test was derived from analysis of graphic representations of the movements on a computer visual display unit (Figure 2). A cursor was used to locate the midpoint of the peak plateau, which represented the final positions chosen by the person. Initial overshoot, which sometimes occurred in the process of returning to positions, was ignored.

Statistical Analysis. Within-day variation in repositioning errors was analyzed using a single-factor analysis of variance (ANOVA). Between-day variation was assessed using a nested ANOVA. In both cases, the intraclass correlation coefficient (ICC) was also calculated. This was used to estimate the reliability of repeated measurements both within and between days. All statistical tests were two-tailed, and a significance level of 5% was adopted.

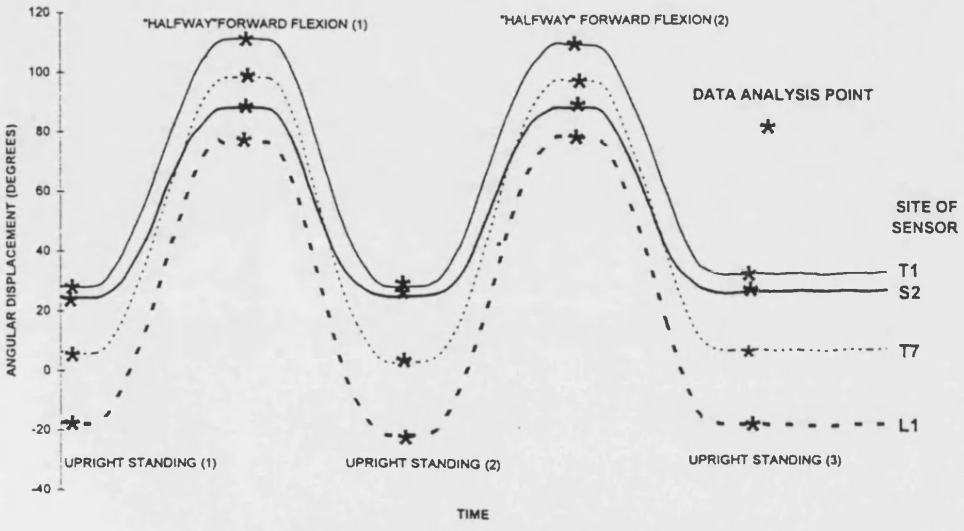

Figure 2. Angular measurements for each sensor location were taken from the midpoint of the plateau representing the final positions chosen by participants (as indicated by the asterisks).

Table 2. Within Day Reproducibility of Position Sense Measurements

	T1			T7			L1			S2		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Flexion day 1												
"Halfway"												
Mean	3.86	3.97	5.94	3.74	4.35	5.81	4.01	3.60	6.10	2.22	1.75	3.35
SD	2.55	2.93	6.17	3.17	2.80	5.71	3.38	2.87	6.04	2.04	1.03	1.65
Within day (*P*)	0.22			0.27			0.16			0.01*		
Upright standing												
Mean	3.80	4.49	3.07	2.93	3.05	2.69	2.2	2.12	2.45	1.49	1.68	2.11
SD	3.13	2.47	1.84	1.82	1.22	1.91	2.03	1.53	2.49	1.23	1.57	1.80
Within day (*P*)	0.22			0.79			0.87			0.44		
Right side flexion day 1												
"Halfway"												
Mean	3.16	2.62	3.69	2.64	1.86	3.70	1.98	1.20	1.98	0.43	0.49	0.54
SD	3.02	2.49	1.99	2.63	1.82	2.07	1.76	1.28	1.26	0.35	0.44	0.47
Within day (*P*)	0.42			0.04*			0.15			0.71		
Upright standing												
Mean	1.81	2.22	2.43	2.08	2.47	2.25	1.63	1.95	1.47	0.34	0.39	0.52
SD	1.12	1.70	2.21	1.26	1.69	1.24	1.34	1.17	0.25	0.25	0.36	0.44
Within day (*P*)	0.52			0.75			0.50			0.28		
Left side flexion day 1												
"Halfway"												
Mean	3.01	3.72	3.89	2.97	3.18	3.05	2.25	2.03	2.30	0.85	0.82	0.80
SD	2.44	3.03	2.43	2.38	2.24	1.81	2.28	1.55	1.80	0.77	0.73	0.90
Within day (*P*)	0.54			0.95			0.89			0.98		
Upright standing												
Mean	1.66	2.15	2.32	2.31	2.32	1.99	1.13	1.50	1.16	0.36	0.47	0.40
SD	0.83	1.99	1.44	1.23	1.48	1.45	0.89	1.85	1.05	0.26	0.54	0.34
Within day (*P*)	0.21			0.58			0.42			0.52		

* Statistical significance. Results are quoted to two decimal places.

■ Results

Within-Day Reproducibility of Joint Position Sense Recordings

Mean values of active position sense for the three trials carried out on day 1 are shown in Table 2. In most within-day comparisons, there was no significant difference in position sense between tests in either the sagittal or coronal planes. The exceptions to this were a significant variation for forward flexion at S2 ($P = 0.01$) and for right side flexion at T7 ($P = 0.04$). Intraclass correlation coefficients between the repeated trials carried out on day 1 are shown in Table 3. In the sagittal plane, the correlation was generally good, with values lying between 0.61 and 0.70 except at S2, where lower values were observed. In the coronal plane, values were more variable than in the sagittal plane, particularly in left side flexion, which represented the non-dominant side in 17 of the 20 participants.

Day-to-Day Reproducibility of Joint Position Sense Recordings

Average values of position sense over the three tests carried out in each position on days 1 and 2 are shown in Table 4. Day-to-day comparisons of values obtained for forward flexion and left and right side flexion revealed no significant differences in position sense within participants. However, there was a significant variation on return to upright standing from left side flexion at L1 ($P = 0.015$) and S2 ($P = 0.002$).

Figures 3 to 5 show mean values of position sense for "halfway" flexed and upright positions on days 1 and 2. Position sense tends to become more accurate from cephalad to caudad and is in general better in upright than in "halfway" flexed positions.

Intraclass correlation coefficients between measurements obtained on days 1 and 2 were calculated in two

Table 3. Within Day and Day-to-Day (Average of Three Tests in Each Position) Intraclass Correlation Coefficients (r)

	Forward Flexion		Right Side Flexion		Left Side Flexion	
Sensor	Upright Standing	"Halfway"	Upright Standing	"Halfway"	Upright Standing	"Halfway"
T1						
Day 1	0.697	0.622	0.747	0.658	0.102	0.111
Day 1/2	0.572	0.790	0.755	0.682	0.114	0.709
T7						
Day 1	0.614	0.636	0.739	0.521	0.681	0.379
Day 1/2	0.570	0.832	0.781	0.670	0.261	0.658
L1						
Day 1	0.605	0.618	0.748	−0.366	0.621	0.631
Day 1/2	0.715	0.898	0.722	0.428	0.261	0.339
S2						
Day 1	0.434	0.124	−0.127	0.557	0.577	−0.345
Day 1/2	0.722	0.386	0.434	0.428	0.291	0.661

Table 4. Day-to-Day Reproducibility of Position Sense Measurements

	Upright Standing Positions						"Halfway" Positions					
	Forward Flexion		Right Side Flexion		Left Side Flexion		Forward Flexion		Right Side Flexion		Left Side Flexion	
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
T1												
Mean	3.79	3.01	2.15	1.95	2.04	1.99	4.59	5.26	3.15	3.26	3.53	3.70
SD	2.56	2.65	1.73	1.60	1.28	1.48	4.25	3.53	2.53	2.59	2.63	2.62
P	0.26		0.17		0.13		0.70		0.10		0.89	
T7												
Mean	2.89	2.04	2.26	2.04	2.21	1.70	4.64	5.27	2.73	2.90	3.06	2.90
SD	1.66	1.55	1.59	1.50	1.38	1.25	4.13	3.47	2.29	2.44	2.12	2.40
P	0.25		0.07		0.12		0.79		0.54		0.75	
L1												
Mean	2.25	2.52	1.68	1.72	1.26	1.80	4.57	5.17	1.72	1.86	2.19	2.15
SD	2.02	1.89	1.30	1.24	1.00	1.34	4.40	4.92	1.48	1.72	1.87	1.69
P	0.27		0.46		0.02*		0.91		0.30		0.14	
S2												
Mean	1.76	1.67	0.41	0.40	0.41	0.55	2.44	2.87	0.49	0.44	0.82	0.66
SD	1.55	1.50	0.35	0.29	0.40	0.44	1.74	2.56	0.42	0.46	0.79	0.68
P	0.83		0.44		0.002*		0.22		0.14		0.98	

* Statistical significance. Results are quoted to two decimal places.

separate ways: by comparing individual values for each trial on each day and by comparing averaged values obtained on day 1 with those obtained on day 2. The latter comparisons provided the best correlation coefficients, and these are shown in Table 3. The range and variability of the ICCs tended to reflect those obtained for the within-day trials, with the values obtained in left side flexion being the lowest and most variable.

■ Discussion

There has been a continuing debate concerning the validity of skin surface measurements of spinal motion. This has arisen largely because variable skin movements can result in considerable measurement errors, particularly in the modified Schober test, which uses the separation of skin markers to estimate lumbar motion.[30] Measurements of lumbar motion using a flexicurve also have been reported to give only reasonable accuracy (± 25.5%) compared with radiography;[38] in this particular study, however, the discrepancies may have been a result of measurements being made on different days and in different test positions. Simultaneous measurements of lumbar range of motion using electronic inclinometers and radiography previously have been compared in the author's laboratory, and good correlation was observed ($r = 0.91$) between the two.[2] Furthermore, measurements of the lumbar range of motion obtained using another skin surface device, the 3-Space Isotrak, give means and ranges of values similar to those obtained from radiographs in an age-matched group of people.[12] In the current study, the Fastrak sensors were attached in a similar manner to the inclinometers and Isotrak used previously,[2,12] so the values of spinal motion should reflect true angular movements of the underlying spine.

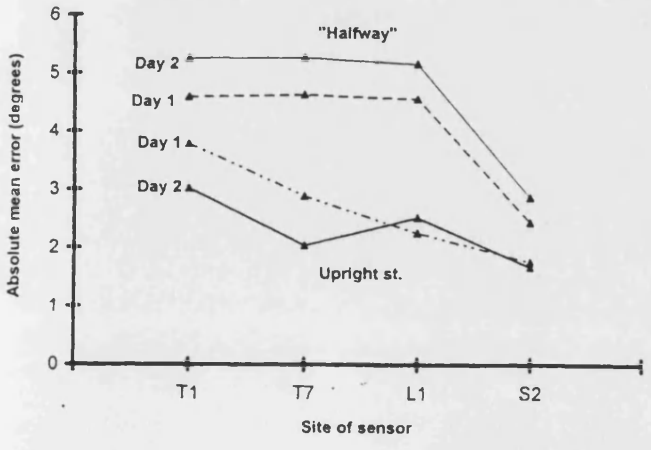

Figure 3. Repositioning errors on day 1 compared with those on day 2 for upright and flexed "halfway" positions in the sagittal plane.

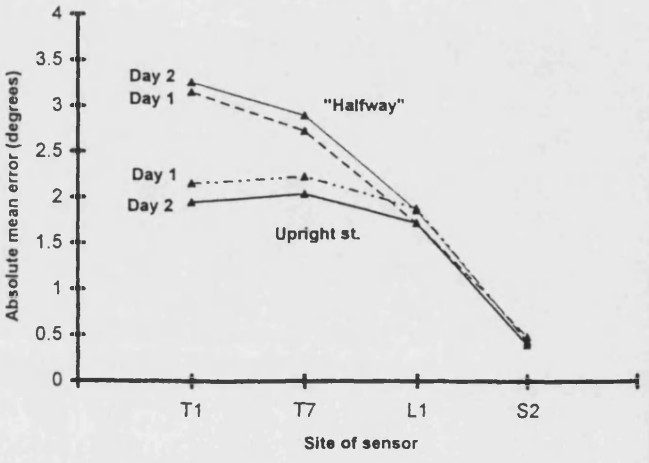

Figure 4. Repositioning errors on day 1 compared with those on day 2 for upright and flexed "halfway" positions in the frontal plane (right side flexion).

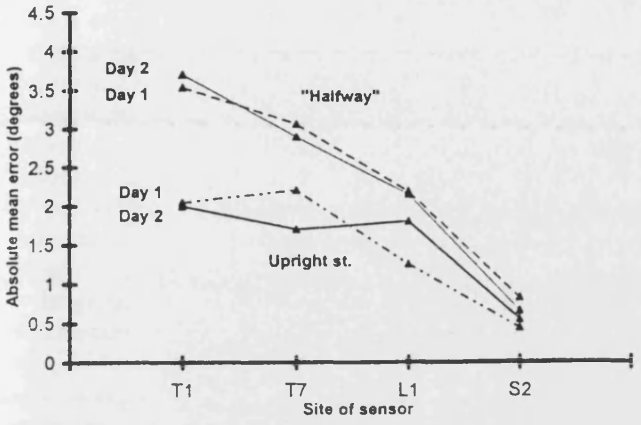

Figure 5. Repositioning errors on day 1 compared with those on day 2 for upright and flexed "halfway" positions in the coronal plane (left side flexion).

Within-Day Reproducibility

The results of the current study have shown that healthy volunteers are capable of reproducing spinal positions in the sagittal and coronal planes with reasonable accuracy. Measurements made on the same day revealed no evidence of a systematic fatigue or training effect between the three repeated tests. Parkhurst and Burnett,[29] using custom-made spinal motion apparatus to assess three different aspects of proprioception, similarly found no evidence of learning or other systematic influences between three repeated tests of repositioning accuracy in the lower back. The significant within-day variations observed in the current study in two of the sensor positions were not seen on the second test day, and visual inspection of data for both sensors showed no systematic trend between the three tests (Table 2). Furthermore, the repeated "halfway" measurements in right side flexion at T7 had a reasonable ICC, suggesting that this result, which just reached significance, may be spurious. The more highly significant difference at S2, however, was accompanied by a low ICC, suggesting poor reproducibility at this sensor in the "halfway" forward flexed position.

Day-to-Day Reproducibility

Day-to-day comparisons showed that there was no significant difference in position sense measurements in most cases. The only exception to this was in the return to upright standing from left side flexion, where the sensors showed an increased repositioning error on the second day at L1 and S2 (Table 4). The significant difference at S2 corroborates that found for within-day tests at this level and again reflects the low ICC and poor reproducibility at this sensor location. Here the repositioning error is so small (0.41–0.55°) that the values are approaching the limit of accuracy of the measurement device. The significant difference at L1, together with the generally poor ICCs for return to upright standing from left side flexion, may be related to side dominance because 17 of the 20 participants were right handed. A study of trunk positioning accuracy in children aged between 7 years and 18 years suggests that repositioning accuracy on returning to upright standing is better when performed from a right trunk offset.[4] The handedness of the children was not ascertained, although it is likely that most would have been right handed, as in the general population. In the current study there was no comparable difference in position sense on return to upright standing from the right and left, although there was a trend for position sense to be slightly better at the "halfway" positions when flexing to the right. However, the possibility of a lateral dominance effect requires further investigation.

Comparison With Other Studies

The sensors used in this study were small (1.4 cm × 2.2 cm × 2.7 cm) but nevertheless required some fixation with adhesive tape, as described earlier. When questioned at the end of the procedure, no participant reported receiving help from exteroceptive cues or even awareness of the sensors placed on his or her back during testing. There is some evidence from studies on peripheral joints that pressure applied circumferentially by devices such as elastic bandages may facilitate proprioception.[5] However, in the current study, the Hypafix tape that was applied directly to the skin was thin and stretched easily with movement, thus minimizing any extraneous contribution from cutaneous or subcutaneous receptors that might enhance proprioceptive acuity.

The repositioning errors reported in this study are comparable with those reported for the knee joint and the cervical spine.[7,25,31,36] However, other investigators who have measured position sense in the coronal plane in the thoracic spine report mean results at T1 between 0.9° to 2.5° in children and between 0.5° to 0.9° in adults.[4,19] These values are somewhat lower than those observed in the current study, and this may be explained by differences in the test conditions. In the current study, subjects were allowed to move freely in all planes and no restraining devices were used. In the aforementioned studies, the inclusion of a restrictive strap around the pelvis[4] or pelvis and legs[19] may have supplied valuable exteroceptive cues to movement, thus making position sense errors smaller. Furthermore, these studies calculated angular displacement at T1 from linear measurements of the distance between S1 and T1.[4,19] The validity of such measures has not been assessed directly, but although linear measures of spinal motion have been shown to be inherently less variable than angular measures, they also have a poor correlation with true angular movements of the vertebra.[30]

In the current study, proprioceptive measurements were taken from sensors placed directly on the skin overlying the spinous processes, and angular measures were recorded from these sensors rather than subtended from lower levels of the spine, as in some previous studies.[4,19]

Results of proprioceptive studies at other levels of the spine similarly provide a difficult basis of comparison because of the use of indirect and linear measurement techniques, but they suggest higher active position sense values commensurate with those obtained in the current study. Revel et al,[31] for example, reported an absolute mean error of 3.44° for position sense in the healthy cervical spine in the sagittal and transverse planes. More recently, a study by Maffey-Ward et al[24] used the 3-Space Fastrak to measure position sense in the lumbopelvic region of the spine (T10–S2). They reported mean repositioning errors of 2.6° in healthy volunteers attempting to reproduce the upright posture after sagittal plane movements. These findings are in close agreement with those of the current study for this region of the spine.

In general, standard deviations of the position sense measurements were characteristically low, especially in upright standing. Two of the 20 subjects were notably poor at reproducing some of the positions. These differences between individuals may in part reflect cognitive processes such as judgment, decision making, and concentration. There was also a trend for repositioning errors to increase from caudad to cephalad, particularly in coronal plane movements, and this probably reflects the increasing number of joints involved in producing the movement on ascending the spine. Indeed, in forward flexion, the repositioning error at each sensor location was fairly consistent (5–6%) when expressed in terms of the total range of movement traversed by the sensor in full range movement.

A further observation made in the current study was that position sense in upright standing was superior to that in flexed positions (Figures 3–5). It is possible that the vestibular apparatus, input from which cannot be prevented, provides more help in maintaining the upright posture than it does in maintaining less commonly adopted positions. Position sense in the coronal plane is consistently better than in the sagittal plane for upright and flexed postures (Table 4). This may reflect the contribution of proprioceptive input derived from skin contact in lateral bending.

■ Summary

This study demonstrates that the 3-Space Fastrak provides reproducible results when used to measure active position sense of the spine. Variations in position sense due to factors such as the positioning of sensors by the same operator, fatigue, and practice do not appear significantly to affect the reproducibility of results within individual subjects. Position sense measurements extrapolated from the average absolute repositioning error of three randomized tests at T1, T7, and L1 in "halfway" positions in forward flexion and on return to upright standing from right side flexion are the most reproducible. These measurements are therefore likely to provide the best basis for comparison between different subject groups in proprioceptive studies. Repositioning errors tend to increase on ascending the spine, and this probably reflects the increasing number of joints involved in producing the movement. Poor reproducibility of position sense on return to upright standing from the left may be the result of a lateral dominance effect, which warrants further study. The position sense results of this study accord with those of other studies of position sense in spinal and peripheral joints.

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